CCC2018

CREATIVE CONSTRUCTION CONFERENCE

30 June - 3 July 2018 Ljubljana, Slovenia




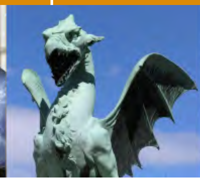


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Table of Contents:

Automation and Robotics in Construction

Creative Construction Technology and Materials

Creative Management in Construction

Creative Scheduling in Construction

Sustainable Construction, Health and Safety

Visualization, Virtual Reality for Design and Construction, Building Information Modeling (3D, 4D, nD)

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A novel approach to develop vertical city utilizing construction automation and robotics

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Abstract

As a sophisticated organism, a city has an essential characteristic, which is the ability to constantly and flexibly transform throughout its lifecycle in response to economy shifts, demographic change, and environmental pressures. Nowadays a number of new developments are claimed in the name of "vertical city", yet few represent this important characteristic. This paper aims to propose a novel approach of vertical city, or in other words Dynamic Vertical Urbanism, featuring constant vertical urban transformation by applying the state-of-the-art construction technologies. First, successful and unsuccessful precedents of building complexes which inspire this novel concept will be analyzed. In addition, building technologies that are crucial to the implementation of this approach will be introduced. As a result, this vertical city concept has the ability to integrate five basic elements of a city: vertical and horizontal circulation systems as its paths, a flexible building envelope as its edges, variable mix-used functional blocks as its districts, sky bridges and roof gardens as its nodes, and the complex itself as a landmark. More importantly, it can change its size, form and function with the help of construction automation technologies and open building principles, and responsively evolve in accordance with social, economic, and environmental shifts in a self-sufficient manner, meanwhile avoiding the risk of being homogeneous with surrounding buildings. Finally, the complex will perform as a series of interconnected components which act together to form a living organism that performs various functions and purposes such as office, residential, commercial, school, hospital, police station, and infrastructure. In conclusion, this report will provide researchers, architects and urban designers with a valuable example for the future vertical city developments and beyond.

Keywords: Construction automation; modularization; on-site construction factory; open building; vertical city; Vertical Dynamic Urbanism

1. Introduction

A city is a sophisticated organism which is constantly changing throughout its lifecycle, as a result of economy shifts, demographic change, and environmental pressures. Nowadays, megacities in China are facing unprecedented issues such as overpopulation, population aging, land shortage, lack of infrastructure, and environmental pressures during the process of uncontrollable urban sprawl. Meanwhile, a considerable number of new developments claim themselves in the title of "Vertical City", yet very few represent the essence of a city. The definition of vertical city cannot be solely judged by its height, usage or investment return, but has to demonstrate the capability of adaption in response to urban transformation. This paper aims to propose a novel approach of vertical city, or in other words Vertical Dynamic Urbanism, featuring constant vertical urban transformation through applying the state-of-the-art construction technologies. Meanwhile, this vertical city approach has the ability to integrate basic elements of a city: vertical and horizontal circulation systems as its paths, a flexible building envelope as its edges, variable mix-used functional blocks as its districts, sky bridges and roof gardens as its nodes, and the complex itself as a landmark. More importantly, it can change its size, form and function with the help of construction automation technologies and open

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building principles, and responsively evolve in accordance with social, economic, and environmental shifts in a self-sufficient manner, meanwhile avoiding being homogenized with surrounding buildings. Eventually, the complex will perform as a series of interconnected components which act together to form a living organism that performs a variety of functions and purposes.

2. Methods

In this section, two building complexes with opposite destinies, which inspire the Vertical Dynamic Urbanism approach, are demonstrated. In addition, urban design theories and building technologies that are crucial to the implementation of this approach will be introduced.

2.1. Lessons learned from two American building projects

Commonly a building will face an unpleasant destiny when it reaches the end of its lifecycle: to be demolished. Designed by renowned architect Minoru Yamasaki, Pruitt-Igoe, St. Louis is arguably the most infamous failure of American social housing program. Due to poverty, crime, and racial segregation, the overscale complex of 33 buildings were demolished with explosives in 1972, which later became a symbolic event of unreasonable planning and waste of construction resources [1]. This is largely because the traditional building lacks flexibility and variability in its volume, height, and usage (see Fig. 1).

Fig. 1. Aerial view of the Pruitt-Igoe complex. Image courtesy of United States Geological Survey (Public Domain).

2.1.1. Blue Cross Blue Shield Tower, Chicago, Illinois

Contrary to Pruitt-Igoe, a silver lining can be observed in the design and construction process of Blue Cross Blue Shield Tower in Chicago, Illinois, which is a 57-story two-phased, vertically expanded office tower. The building's 33-story first phase was completed in 1997, and more than 10 years later in 2010, phase two was completed, adding 24 stories on top of the original, fully occupied building. During the expansion process, occupation in the lower original building remains normal and uninterrupted [2]. This example shows that through the innovative concept of vertical expansion, a building can successfully plan for a long-term growth without relocation, thus providing an excellent reference for the future expansion of vertical city (see Fig. 2).

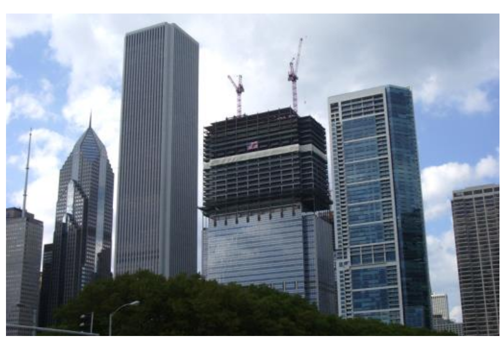

Fig. 2. Blue Cross Blue Shield Tower in Chicago under expansion. Image courtesy of Wikimedia user Photogal (Own work, https://commons.wikimedia.org/wiki/File%3ABlue_Cross_Blue_Shield_Tower.jpg).

2.2. State-of-the-art technologies to be applied in the new vertical city approach

In order to achieve perpetual vertical urban transformation, there are several interconnected concepts and technologies which will serve as the core pillars of Vertical Dynamic Urbanism (see Fig. 3). These concepts and technologies will be analyzed in the following sections.

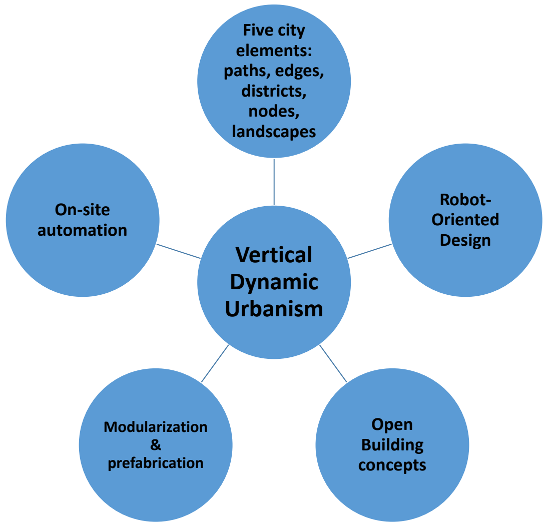

Fig. 3. Five pillars in the new vertical city approach.

2.2.1. Five city elements

In the book the Image of the City (1960), Kevin Lynch concluded that people formed mental maps of the surrounding urban area through five tangible elements: paths, edges, districts, nodes, and landmarks [3]. Accordingly, in order to achieve the authenticity of a vertical city, these five elements must be interpreted and reflected in the design process. Specifically, the new vertical city has vertical and horizontal circulation systems as its paths, a flexible building envelope as its edges, variable mix-used functional blocks as its districts, sky bridges and roof gardens as its nodes, and the complex itself as a landmark.

2.2.2. Robot-Oriented Design

First conceptualized by Thomas Bock in 1988, Robot-Oriented Design (ROD) emphasizes the idea that before the final on-site construction process, all parameters shall have been already considered at the earlier design and production stages. In order to establish determined conditions for robotic on-site operations, the elements of building subsystems (e.g. building structure, component, assembly method, and equipment selection, etc.) need to be geometrically and physically well defined in accordance with robots and automation [4].

2.2.3. Open Building concepts

Open Building is a cross-disciplinary approach to the design of buildings that takes account of the possible need to change or adapt the building during its lifecycle, in accordance with social, economic, and technological changes. Open Building concepts gradually emerged in response to evolving social, political and market forces, to prevailing conditions and trends in residential construction, manufacturing and many other factors that demand more efficient and susceptive practices. The building is designed in different levels: support structure, infill system, fit-out and appliances [5]. All these levels have been updated and reinterpreted to utilize the benefits of state-of–the–art industrial production, emerging information technologies, improved logistics and changing social values and market structures. Apparently, buildings following Open Building principles will by no means become obsolete, but will perpetually evolve in accordance with occupants' demands.

2.2.4. Modularization and prefabrication

Modularization and prefabrication play a significant role during the lifecycle of the new vertical city approach. Usually several levels are defined in building prefabrication: lower-level components made of raw materials and parts (e.g. ceramic, brickwork, concrete, wood, steel, glass, polymers, etc.), mid-level building components (i.e. building subsystem manufacturing, such as kitchen modules, bathroom units, assistance modules, etc.), and high-level prefabricated complete buildings [6]. In the new vertical city approach, all main parts and components of the building will be prefabricated in coordination with Open Building concepts, in order to achieve flexibility and sustainability throughout the lifecycle of the vertical city.

2.2.5. On-site automation

Since the late 1980s, Japanese contractors began to realize that payoffs of single-task robots were limited unless more of the construction process could be automated and integrated. Therefore, they began to explore the application of manufacturing principles to construction. There are four fundamental elements in an on-site automation system: (1) an on-site factory protected by an all-weather enclosure, (2) an automated jacking system, (3) an automated material conveying system, and (4) a centralized information control system. Most of the on-site construction factories use just-in-time material delivery system, bar-coded parts or components, and computerized information management system to improve the efficiency and quality of the construction process. Other tasks such as welding, painting, and concrete finishing can be further carried out by single-task construction robots. In addition, the on-site construction factory system can also be applied to the deconstruction process.

For example, Big Canopy, designed by Obayashi Corporation in 1995, was the first automated construction system applied in the construction of precast concrete structures. The Big Canopy itself is supported by four mass independent columns around the building which allow more flexibility than other previous systems. The system has a self-climbing temporary roof. Once the floor was erected, the canopy is jacked up one story at a time and always left a two-story space in between the canopy and the on-site factory floor. Furthermore, the system has a parallel material delivery system which consists of overhead cranes and material delivery lifts (see Fig. 4a).

HAT Down method, developed by Takenaka Corporation, is a closed sky factory supported by building itself (moving downwards). The HAT Down system, which can be seen as a reversed on-site construction factory, consists of a series of integrated subsystems: sky factory roof structure, climbing system, horizontal delivery system, lowering shafts, material handling, sorting, and processing yard, real-time monitoring and management system, templates for cutting. In addition, deconstruction site requires some new types of end-effectors, such as material sorting for recycling, water-cutting, and laser-cutting (see Fig. 4b) [7].

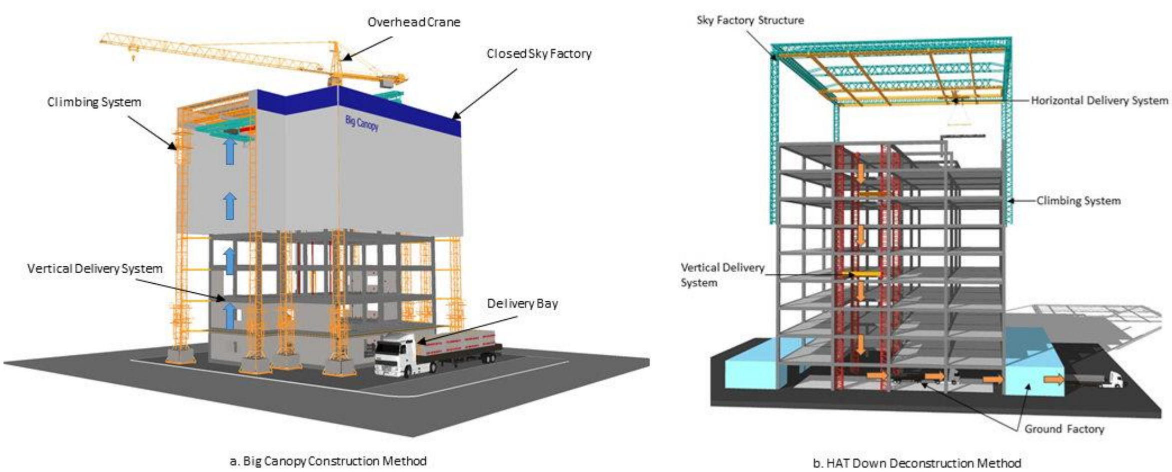

Fig. 4. Comparison of Big Canopy Method and HAT Down Deconstruction Method.

3. Results

3.1. Design overview

The proposed design demonstrates a type of floor plan that is commonly seen in China's construction industry. There are four wings allocated around the central core structure. Each wing consists of ten units, which can be flexibly used as residential, commercial, office, and public use (e.g. school, hospital, police station, infrastructure, etc.) that depends on the requirements of the stakeholders. There are dedicated void spaces located on either side of the wing where the on-site factory self-climbing structures are located (see Fig. 5 & 6).

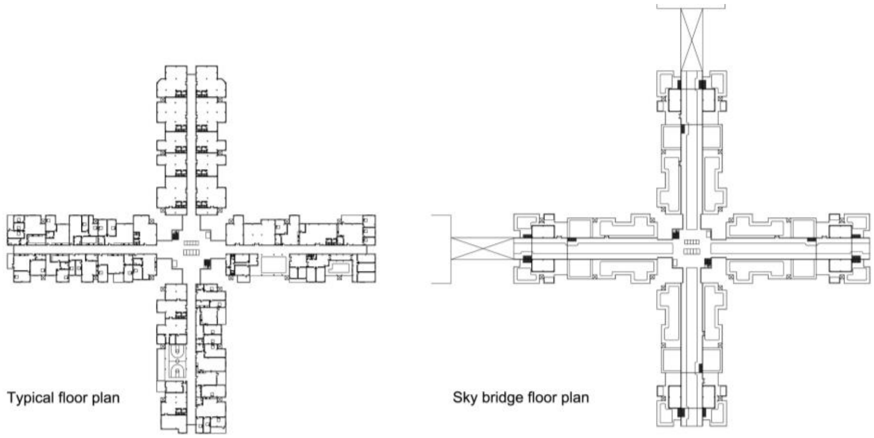

Fig. 5. Typical floor plans in the Vertical Dynamic Urbanism complex.

Fig. 6. Aerial view of the proposed complex following Vertical Dynamic Urbanism principles.

3.2. On-site construction factory

On-site construction factories play a crucial role in the development of Vertical Dynamic Urbanism. With the help of the industrialized building design and the utilization of automation technology, the proposed concept attempts to transform conventional construction sites into on-site assembly environments. Inspired by self-climbing crane and special crane application in the ship building industry, the on-site construction factory (OCF) is designed to assemble the building with minimal human intervention. There is a perpetual OCF responsible for the erection process on top of each tower. Each one of them can independently function, extend and retract, and they operate under a specific protocol that improves construction efficiency and safety (see Fig. 7).

When the section of the wing is completed, the OCF will be retracted, hoisting equipment will be dissembled, and the vacant frame structure will be lowered in to position and functions as the roof of the building. Apart from the central OCF, each wing OCF equips two automated gantry cranes. The gantry crane will cover the entire construction shop floor of the building. The central OCF benefits from an automated gantry crane and a jib crane. The jib crane is responsible for vertical material transportation for the central OCF and carrying out the initial construction of the other four OCFs.

The hoist module functions as the end effector of the automated gantry crane, which is equipped with the smart crane hoist system to keep delivery balanced as well as to provide vertical and horizontal transportation of the building components. The hoist module also equipped with a sensor-controlled configuration system to help identifying the location of the panel and following pre-programmed assembly sequences [8]. The motion displacement of the robot can be manually operated, and in case of emergency, it will switch into an autopilot control system. The robot control system is connected with the main site control facilities and the project management information system [9]. Once the building components with auto alignment feature reach the correct assembly location, the connections will be fastened by means of dry connection method. Welding and on-site casting will be implemented by single-task construction robots to increase assembly speed.

The vertical material transportation platform is controlled by a lifting planning system that generates a lifting plan based on data such as floor heights, acceleration distance, reduction time, number of stops, construction material input speed, lifting cycle, material transfer speed and waiting time. The data required can be collected from the RFID and ZigBee sensors which are located on the building structure or embedded in the building materials [10]. The base of each tower will function as material loading, sorting and pick-up station during the construction, expansion and maintenance process. A programmable logic controller (PLC) is used for controlling the picking system. At the off-site factory, each building component is allocated a RFID tag. When they arrive on site, the tag will be scanned and the information will show the exact assembly sequence and assembly position of each component. Then the components will be placed onto the picking station in the correct order, being ready for lifting and assembly [11].

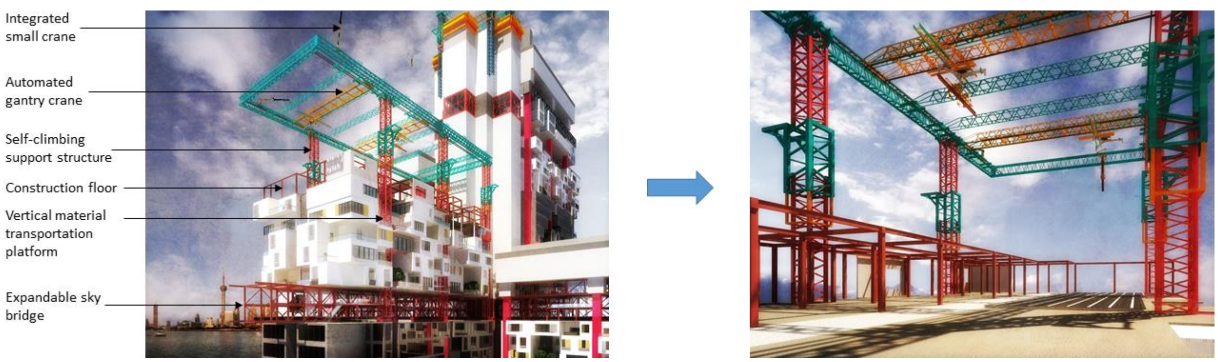

Fig. 7. Exterior and interior views of the on-site construction factory.

3.3. Sky bridge

The sky bridge, which serves as the main horizontal paths connecting different towers, as well as a community gathering space for multiple activities, will be assembled by the correspondence OCF that depends on the direction where the sky bridge will reach out. The OCF will be extended out by using a smaller integrated crane on the upper deck of the mainframe structure. Then the sky bridge will be constructed by the automated gantry crane. Eventually, the sky bridge shall be interconnected from either side by using integrated retractable assembly systems (see Fig. 8).

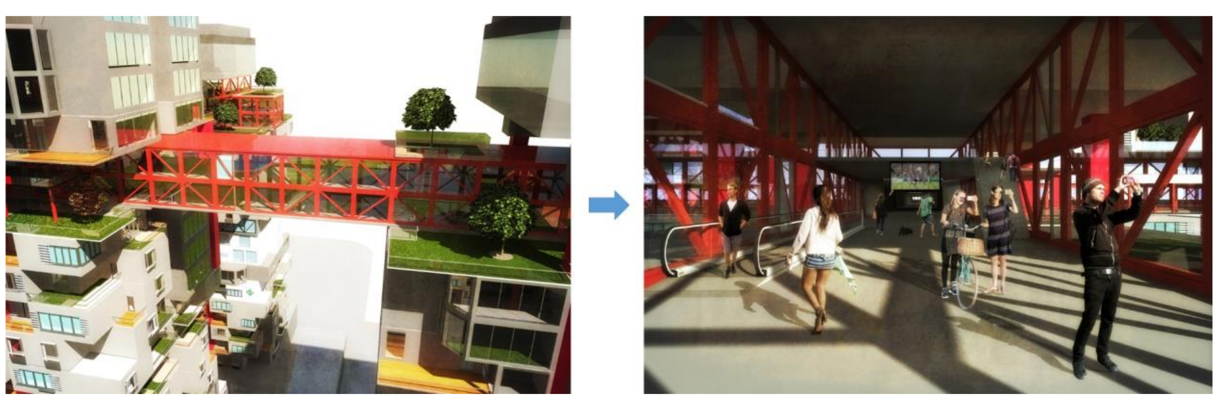

Fig. 8. Exterior and interior views of the sky bridge.

3.4. Open building approach

Following Open Building concepts, building system of Vertical Dynamic Urbanism can be divided into 4 subsystems: structures, non-load bearing components, services and construction. In general, structural systems include a series of steel beams and columns that are interconnected and provide a flexible box-shaped support system. The prefabricated concrete double ribbed floor panel also classify as part of the structural system. Non-load bearing component systems include precast concrete floor panels and sandwich wall panels. Services system consists of interior fixtures, electrical, plumbing fixtures, and heating, ventilation and air conditioning (HVAC) of the building. Each part can be easily assembled or disassembles so that the building system is able to be upgraded or modified according to the specific demand of each end-user (see Fig. 9).

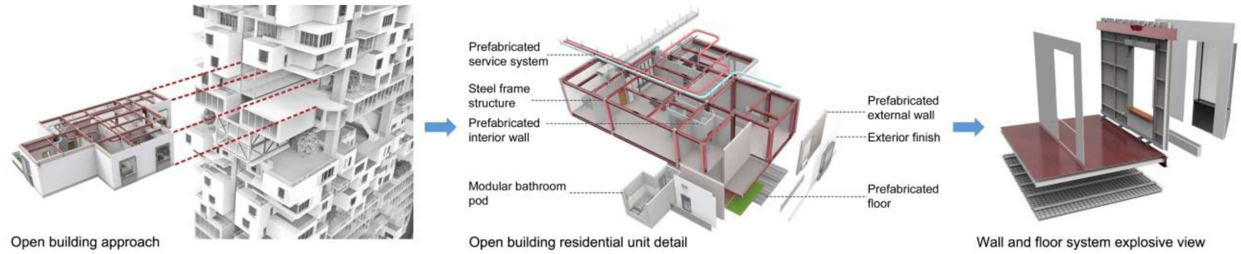

Fig. 9. Open building analysis in Vertical Dynamic Urbanism.

3.5. Development scenario

In general, the construction of the building follows a bottom-up approach, working from the ground section up. The construction sequence consists of six main procedures. First, the assembly of the initial on-site construction factories. Second, structural assembly, in which the steel beams, columns and the floor components are assembled. Third, external façade finishing. Fourth, service installation, and interior decoration. Fifth, preparation or removal of the temporary installation fixtures, anchor systems. Finally, the entire OCF will be jacked up by the self-climbing structure. The building component will be installed following a programed pattern, a specific sequence of crane and robot manipulations will occur which synchronized by the project control program. When reconfiguration of the building is required, the interior can be easily modified; when relocation and deconstruction are required, deconstruction can be conducted in a reversed order to the construction process. One possible scenario for the future development over the lifecycle of a complex following Vertical Dynamic Urbanism principles is envisioned in Fig. 10, and a future vision of this complex is visualized in Fig. 11.

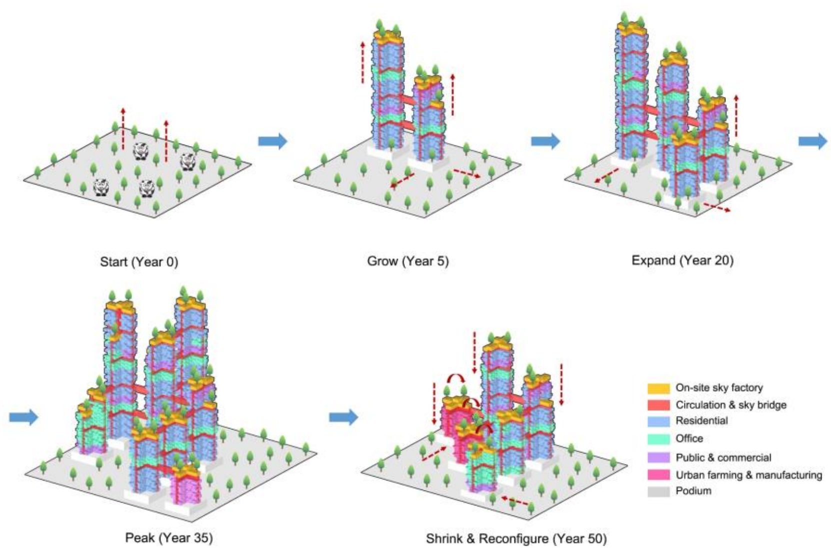

Fig. 10. A typical scenario of 50-year development of a Vertical Dynamic Urbanism complex.

Fig. 11. The future vision of a Vertical Dynamic Urbanism complex.

4. Conclusion

This paper provides a rethink of vertical city in the name of Vertical Dynamic Urbanism, enabling constant vertical urban transformation by applying the state-of-the-art building concepts and technologies. Five interconnected concepts and technologies constitute Vertical Dynamic Urbanism, including five city elements, Robot-Oriented Design, Open Building concepts, modularization and prefabrication, and on-site automation. In addition, this paper will raise public awareness and promote involvement for the research and development of construction automation and robotics. Furthermore, this paper can assist architects and urban planners to formulate a future framework for building design, urban planning, and policy-making process, which will benefit all potential stakeholders, and provide an inspiring way of thinking to tackle the aforementioned serious issues such as overpopulation, population aging, land shortage, lack of infrastructure, and environmental pressures. Nowadays, due to the improvement of medical care standard, the enhanced social security level, as well as the implementation of the three-decade long one-child policy (recently replaced by two-child policy since 2015), China is about to accelerate into an aging society [12]. Meanwhile, issues such as rapid urbanization, severe environment pressure, and increasing labor costs will further challenge the stability and sustainability of China's development. Given that the technical barriers for the popularization of construction automation technology have disappeared thanks to the rapid development of information technology and robotics, the construction automation technology will soon provide a great opportunity to tackle those critical issues. It is foreseeable that in the near future, construction automation will play a significant role in the development of China and beyond.

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Are computers agents? Considering the implication of classifying computers as occupants on energy consumption and proximity-as-utility equipment scheduling

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Abstract

Non-ancillary equipment makes significant contribution to building energy demand, consuming as much as half of total energy consumption and three quarters of consumption during inoccupancy. Current proximity-as-utility equipment scheduling does not reflect physical or social complexities of mediating equipment, failing to suitably represent equipment and seemingly incompatible with inoccupancy scheduling. This paper draws comparison between computers and conventional occupants attempting to identify the extent which it is applicable to energy modelling. It concludes with the concession of its lack of relevance in inoccupancy equipment scheduling, though inherently convenient and suggests partial decoupling of agents and non-ancillary equipment during occupancy.

Proximity-as-utility is herein defined as equipment scheduling defining utility as a Boolean-state power density necessitating the presence of a proximal agent, accommodating short periods where equipment and agent do not cohabit a discrete space.

Building simulation; occupant ontology; virtual actors; moral agents

1. *Introduction*

Ostensibly, from the planets in a solar system to people in buildings everything is an occupant and ecosystem to some extent. Each are nested and/or interacting, non-stationary systems with their own diverse occupants. Systems are varyingly persistent and prone to traversal through parent systems. Their relationships with other systems and processes can be mutually exclusive or intricately linked, but even those which are seemingly distal can have a persistent knock-on effect on both physical and optimum state definitions.

The implied feature is being human is not a prerequisite of occupant status, something which is becoming more prevalent in the literature. Furniture for example, in the form of spatially-represented internal thermal masses [1] which Li, Xu [2] note as contrasting with existing model assumption of an isothermal stability between furnishings and the space. Furthering this, Johra and Heiselberg [3] discuss the validated relationship between comfort and

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furnishing, specifically humidity buffering, and indicate the need for further research into the complex effects of furniture.

Previous building physics research discussed what could be considered the impact of equipment personalities on energy demand with [4] identifying an established case for equipment similar to the theme of this article proclaiming "simple workloads" fail to reflect the complexity and variety of user or equipment behaviours. Jones et al effectively discuss the hardware personalities and identify idiosyncrasies in the form of mixed focus software activity, thought they do not consider the relationship between the agent and mediator, the computer. Social science has investigated the effect of perceived humanity in electronic devices on people's behaviours and perceptions of the world around them [5] [6] which is supported by computer ethics literature Johnson and Powers [7],Nonetheless, scheduling for equipment is still largely proximity-as-utility, aggregated power densities.

Current scheduling where consumption is a feature of occupant presence rather than the equipment itself, does not appear to sufficiently encompass the intricacies of non-ancillary equipment and inherently ill-prepared to support equipment scheduling for inoccupancy. However, the extent in which a change to the existing model is required, especially in terms of consumption during inoccupancy, is unclear. This paper discusses non-ancillary equipment scheduling and physical/social personalities using computers, the most significant contributor to plug load and diverse form of non-ancillary equipment, to assess the proposal.

2.1. Structure

Literature from peer-reviewed journals, primarily sourced from Science Direct, were identified which demonstrate the significance of computer energy consumption during occupancy and inoccupancy. Existing research on similar themes of inanimate agents and computer personalities from building servicing and social science literature were used to draw comparison between computers and agents. Observations were aggregated into general statements equipment scheduling to show relevance or lack thereof for classifying computers as agents during occupancy and inoccupancy, separately.

2.2. Precedence

Discussion on disaggregation of occupant-attributed disturbances has received increasing attention over the last few decades. The suggestion that some equipment are closer to being occupants than equipment in the conventional sense has in principle been covered previously in activity detection [4, 8] where appliance-level consumption was considered significant to understanding user behaviours. Jones, Wei [4] discussing system processes and energy consumption implicitly suggest the impact of idiosyncratic personalities of the machines themselves. Personality seems further supported by Joy E, Suart A [9] who note agents are not exclusive to a single computing devices or locations and Gunay, O'Brien [10] who identify significant differences in the energy conscious behaviours of respondents when using differing computer types. Information technology and social science literature makes a contrasting but complementary case for treating computers people and how this naturally manifests in one-way [11] and two-way [6] relationships between people and electronic devices. Similarly, computer ethics research does not consider treating computers as "surrogate" agents a novel idea [7].

2.3. Significance

Equipment operation is often considered a passive occupant behaviour, one which does not interfere directly with ancillary services, yet some forms of equipment are arguably better thought of as agents, closer to the definition of conventional occupants than equipment. It seems like an oversight in taxonomy to simplify it to a passive disturbance from the occupant when plug loads alone contribute 12% to 50% of energy use in offices [10, 12], and up to and beyond 50% of commercial building energy is consumed outwith operational hours [13]. Gunay, O'Brien [10] observed up to 75% of plug load energy use being attributed to out of hours consumption in offices, 70% of plug loads associated with personal computers with around 60% private occupants using desktop computers, only 50% of which report switching computers off at end of day. However, the latter observation is contrary to those of Wang and Ding [14] who observed 90% of users switching off during predictable periods of absence They also notice the appearance of more energy-awareness from laptop users with 25% of computer users reporting never turning off in contrast to only 5% of laptop users and 10% laptop users shutting down during intervals. Jones, Wei

[4] monitored energy consumption to extrapolate and potential energy savings from computer users suggesting global computer energy consumption could be reduced by 17TWh with lower thresholds for standby mode, and 230 – 68GWh through reduction LED backlight intensity, per annum. Though they acknowledge their sample size is too small to make definitive conclusions. An interesting secondary observation was the persistence of web-based advertisements in browser and/or tabs which were not in focus increasing the number of active processes suggesting something as simple an ad-blocking tool could reduce energy consumption. Ethical quandary of ad-blocking aside, these show not only is equipment-level user behaviour monitoring desirable, but the personality of the system itself is worth considering. The problem extends to residential buildings where it is expected equipment energy consumption will tripled by 2030 from 2009 levels [4]. Zhang and Bai [15]'s study of consumer goods ownership in Shangdong identified a 600% increase in computer ownership per hundred urban households between 2005 and 2013 indicating a drastic surge in electronic energy consumers.

Given these observations and case study observation of high utilisation variance [14] it seems evident that non-ancillary equipment are not entirely compatible with proximity-as-utility scheduling as is available with the decoupled scheduling used in DSMs or presence-as-utility in lower-precision models, the latter assuming any presence is merits utility. That is, during occupancy the activities and behaviours of conventional occupants and computers aren't entirely dependent and it's not only the conventional occupants' disturbance to the building ecosystem which isn't steady-state.

2.4. Computer and equipment in buildings

Computers are distinct in building energy contexts from other equipment in several ways but the most significant is their position between ancillary and non-ancillary stationary equipment where the latter can be managed by smart controllable load (SCL) automation [16] and the former's operational schedule is immutable, refrigerators, routers or servers for example. Computers fall under neither category; user inactivity is not an indication of activity or inactivity of the device, but they are mutable and increasingly portable. Additionally, computers and SCLs can have human-mediated relationships both of which can be supported by supervised or unsupervised optimisation [16, 17]. Similarly, computers can dictate conventional occupants' actions whether actively through delivering information or passively through processing affecting occupants' activities within a building, although their mobility is dependent on the conventional occupant, the occupant's behaviours can be guided be the device.

Herein lies the problem, non-ancillary equipment, particularly computers' consumption mutability is situational and a product of the relationship between the conventional occupant, the computer and the collective energy culture of the occupants. In contrast, services follow rules and adapt, and ancillary equipment consumption is immutable. Even disregarding equipment personalities, existing equipment scheduling not reflect divergence between ancillary and non-ancillary equipment personalities.

3. Computers as moral and social entities

Laptops are arguably similar to young children to many building service configurations' interpretations of an occupant in their ecosystem, differing primarily in flexibility of shared characteristics. Both passively contribute heat to the parent ecosystem at activity and environment-dependent rates, depend on adult occupants for mobility, not meaningfully able to interact with the parent ecosystem without adult guidance and appear to stochastically exhibit signs of sentience in varyingly significant and consistent forms. In the case of the latter, people mindlessly treat computers as humans (ethopeia) [6] which they do fairly liberally [18] and adults pretend children have self-awareness beyond the child's age, suggesting similarities in status as social actors and to an extent, the appearance of self-efficacy. In contrast, children do not generate light pollution and computers do not directly emit pollutants affecting humidity or air quality and are entirely reliant on conventional occupants making a distinction between child and laptop readily available to sensor-supported conditioning. Nonetheless, they interact with the environment beyond thermal disturbance through interaction with other inhabitants and immaterial environmental pollution, appearing to favour a less simplistic object model for equipment at least for some non-ancillary devices. Laptops in particular have one characteristic exclusive to portable devices which has been shown to complicate power density reporting [10] , they transfer energy and information between adjacent and/or consumed and distal ecosystems.

Looking at it from computer ethics perspective perhaps best alludes to why social personality is important. Discussing surrogate agency Johnson and Powers [7] notes the presence of spyware or bots as evidence the idea computers are agents, in ethical contexts, is not novel. The statement supports the observation of Jones, Wei [4] on the effect of software on a computer's personality (activity) but its primary relevance to this discussion is defining computers as at minimum, surrogate agents with "second-order interests" akin to the relationship between a lawyer and client. In an earlier article, Johnson [19]Johnson [19] explains "… as with human behavior, when computer systems behave, their behavior has effects on other parts of the embodied world". This is a critical feature of the proposed reclassification, the effect of their behaviour (personality) does not exclusively reside within the mind of the user, which complements Jones et al and Wang's energy and social personalities. However, Johnson later highlights computer systems' intentionality is "inert" or "latent" without the intentionality of the user which, in terms of this article, seems to nullify any significant value in considering computers as agents during inoccupancy.

People assign humanity to computers whilst fully aware of the absurd attribution, nonetheless, they form relationships which are sensitive to the computer's ability to manage its second-order interests, similar to the way an office worker's employment is dependent on their second-order interest, keeping management satisfied. However, a computer's agency is dependent on the intentionality of the user and therefore is removed when the user and latent intentionality expires. This seems suggests computers are agents during occupancy but not inoccupancy.

4. Discussion

Computers share similarities with conventional occupants not quite fitting into any category of equipment, exhibiting similar physical and social characteristics of occupants and developing relationships with the user and world around them. They interact distinctly from other forms of equipment and contribute a significant portion of building energy consumption which was shown to have justification for increasing equipment-occupant interactions modelling precision to software and hardware level. Their contributions to the ecosystem have similarities to young children having dependent mobility and creating a mixture of material and immaterial pollutants causing environmental and social events, arguably with a higher chance of passing the Turing test. That is, the information they transmit to the environment has more utility and capacity to change the environment with greater persistence. Their environment disturbances are also activity-dependent in a manner which is neither Boolean nor reliant on physical or SCL device intervention. Finally, their behaviour is learned from peers though dependent on user intentionality and they can transfer electrical potential and information between environments which, in the case of information does not require spatial proximity.

However, although computers and occupant function are co-dependent in office settings conventional occupants in isolation are independent from computers. Therefore, computers are subordinate to the conventional occupants meaning the stochastic nature of their environmental and social impact do not persist during inoccupancy and effectively are akin to an ancillary device.

The underlying principle of considering computers as more than static sources of disruption and consumption as individual entities sharing characteristics of conventional occupants if only during occupancy is significant and validated by existing research. In terms of inoccupancy it appears the proposal has some merit for filling the absent consumption void of existing proximity-as-utility scheduling however, with computers robbed of agency during inoccupancy there is no necessity for any complex behavioural modelling beyond determining appropriate loads, power state probabilities and durations of inoccupancy.

The transition between agent and equipment status and the resulting Boolean-state power density is difficult to quantify. Jones et al observed a significant number of computer users not powering off yet not so many with laptops. This could be situational or cultural but equally could just be the ergonomic benefits from linking screen hinge angle and power state. Energy-conscious behaviours stem from education and sociocultural pressures which suggests when devoid of personality, the consumption associated with non-ancillary equipment during unoccupied periods is primarily a function of social exposure or the conventional occupant's desire for exposure. If this is the case, then non-ancillary equipment inoccupancy scheduling may be considered culture-as-utility or identity-as-utility depending on the desired granularity.

Jones et al have laid the foundation for the latter with their software, but cultural weighing is beyond the scope of this article or the referenced literature. The authors would recommend future research into cultural consumption and sensitivity analysis for occupant wellbeing assessment.

5. Conclusion

High consumption during inoccupancy, total plug load contribution and supporting device monitoring literature highlight the necessity to re-evaluate the what we consider to be an occupant in building energy simulations or predictions. Treating non-ancillary equipment as subordinate agents rather than simply power densities during occupancy appears to be a necessary feature for researchers investigating energy conservation measures, the performance gap or real-time monitoring but their status changes to a culture-sensitive disturbance during inoccupancy.

This paper proposed non-ancillary equipment, primarily computers, should be considered as agents rather than Boolean-state power densities or features of the conventional occupant. Since the computer's agency is dependent on the presence of a conventional occupant they are subordinate and are effectively fall back to the conventional definition of equipment during inoccupancy. To this end the author maintains the relevance of the premise of computers as agents during occupancy for energy and wellbeing but acknowledges there is little value in considering them as agents during inoccupancy.

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Artificial Intelligence Assisted Professional Work in BIM: A Machine Reasoning Extension

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Abstract

A rule based semantic method is utilised as a model and is demonstrated to tackle the problems of analytical processes. The investigation of BIM-based cost estimation confirmed that industry foundation classes (IFC) can provide construction project semantics but incapable of relating domain semantics and pragmatics. Our model provided the rules that three components are necessary to gain a full awareness of the domain which is being computerised; the information type which is to be assessed for compatibility (syntax), the definition for the pricing domain (semantics), and the precise implantation environment for the standards being considered (pragmatics). This paper outlines the way in which the proposed approach has been verified, by employing a selection of codes created by the prototype of the data based model. The standards of practice which have been established are then verified, in accordance with the actual building information gained from IFC. The utilisation of this approach has significantly advanced the procedure of automating professional costing practice within BIM. These justified outcomes demonstrate that, by implementing this model, the reasoning ability can be used by the BIM context and the restrictions around the application of BIM will be reduced. The BIM platform is directly affected by the IFC file that is housed within the ontological structure which has similarities to the Semantic Web and Logic Programming. The adoption of this methodology has greatly advanced the process of automating complex sets of construction standard, allowing the automation of analytical processes. It also outlines the possible connection between machine learning and machine reasoning in order to facilitate wider adoption of computer aided professional practice.

Keywords: AI; BIM; ontology; rule-based; semantic;

1. Introduction

Attempts have previously been made towards automating the cost estimation process within BIM, and for this reason a broad investigation into intelligent solutions for cost estimation is required [1–5]. The studies cited have been chosen from an assessment of the texts involved from more than 100 places; they have been chosen using significant words, including, semantics model, construction, design, building, built-environment, ontology, resource description framework (RDF), semantic web ontology language (OWL), and IFC (dated between 2002 and 2017).

The examples chosen must help in elaborating on what seeks to be explained, and the reserve human aspects as well. It therefore follows that the worth of a model is in large measure due to the clarity of its linguistic meaning, as clear semantics ensure the conclusions reached are clear and the model can be used, without leaving any room for ambiguity. There are often models made that do not have enough semantic clarity. By way of example, established

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CAD systems put forward developed drawing abilities but hardly ever include the human element, for instance, simple geometrical shapes, because they are do not have proper semantic organisation. The aims of BIMs were twofold; firstly, to design a model that includes depictions of objects in order that the physical world can be shown semantically. The other aim was to provide a database of applicable information that could be used to assist those working in the construction field. Since its inception, BIM has been championed by construction experts for dealing with many longstanding problems. Indeed, BIM software on its own is sufficient to meet the requirements of construction experts. However, given the need for applicable expert assessment, many would like to see BIM combined with the spreading of semantic data.

To adapt to the constantly changing IT world, BIM systems need to become more flexible. They must also become more objective, to include both the analysis of experts and the information gathering methodology. Quantity differences have been reduced because of 'smart building technologies' and 'building information models,' and buildingSMART is derived from IFC to manage quantities emanating from BIM applications.

Those carrying out this research would like to establish a system based on knowledge that links with the advances of BIM. The improvement intends to deal with two widely-recognised problems within the area of cost estimation: P1: compliance with domain standards and P2: the use of personal opinions.

This research paper will first give an overview of the cost estimation semantic model. The methodology used to carry out this research will then be examined before the suggestions being put forward are examined. The iilustrative results will then be given and resulting discussion and conclusions will complete the paper.

2. Background

As a result of technological advances in IT, many software applications have been created and used in relation to construction cost estimates. These include Sage Timberline [6], Innovaya Visual Estimating [7], CostX [8], and Nomitech [9]. Nonetheless, there are drawbacks in the use of this software in the cost estimation process; in BIM cases [10–13], and quantity surveyor cases [14–20], pertinent details still need to be taken from the model, or a 3D model built with the particular purpose of estimating costs. This is all a slow and error-likely procedure; after building the model, measurements must be taken by satisfying specific requirements, such as SMM [21] or Professional Practice Guides [22], to arrive at a priced unit figure. This quantity surveying is difficult and hard to follow through accurately [4].

The most usual type of knowledge representation language used is OWL, although studying the estimates given emphasise that there are four semantic models used. Using OWL as a knowledge representation language for descriptive information is the best known and most widely used. Nonetheless, it is important to point out that this use ignores any concerns in relation to language. As noted by Grzybek et al. (2014), problems show up because there is the lack of a proper link between semantics and practical decisions with systems of knowledge engineering. Therefore, it is necessary to have a more detailed assessment of the results of the estimating process [1–5].

The implementation procedure can be understood as making the elements of the component from symbols of the building product replica, such as the IFC-based model, to pinpoint how these elements are made, and using the advice of construction experts in a standalone capacity to measure or add tasks for building components. The cost figure is then altered to take into account the impact of these changes. The ontology also uses a classification scheme which organises the information into a tree structure. There is a parent node for each node, and each parent node might have many children nodes. Moreover, each child node is a sub-category of the parent node and makes it easier to categorise more precisely. The emphasis is on the condition of the design and the impact this has on price. Despite the classification structure being clearly identified, the language for the model is not specific enough.

The improvements in technology that the construction industry has experienced have been heavily influenced by the most recent internet releases. This is commonly known as knowledge demonstration and permits significant improvements in terms of new methodologies. This strategy must permit interconnected functionality between differing software items, including those that are web-based and well thought out suggestions. In terms of the construction industry, software products need to include the ISO-10303 Standard Exchange of Product Data (STEP). Indeed, the IFC was made as a building model for use in the construction industry and using particular features from STEP. It has led to better building data by the application of semantic technology. The central ambition is to improve building information accessibility by producing information that can be managed electronically.

The most apt representation language is often thought to be OWL, particularly in terms of the visuals because it is efficient, familiar, and well supported. It must be acknowledged that this research does not consider offerings in other languages. However, it is still true that data relating to engineering methods does not feature a large variety of semantics and pragmatics [23].

The prototype designed must be able to develop some understanding whilst allowing individual input. Therefore, judging the worth of the model is in many ways dependent on semantics, given that they allow for accurate results to be produced and the usefulness of the model to be assessed. Semantics are important because if the outputs are vague and open to different interpretations, this tends to be because do not have detailed semantics. The CAD programmes is an apt example, in that they provide developed drawing possibilities but do not have a human dimension (for instance, geometric shapes) because they lack semantic detail. The purpose behind BIM was to build models that made use of object-grounded images and to allow for a setting to be described semantically. In addition, BIM also allows for a resource of information to be included that construction industry experts can find to detect the precise product information they need. Many in the industry have been complimentary about BIM since it was set up as a way of dealing with long-running issues.

3. Methodological Foundation and Research Methods

All aspects of research cannot be considered in detail in a paper such as this and instead, the aim is to provide a precis of the methodology used as a prelude to considering the rational position on cost estimates and the author's assessment of the system that should be developed. An in-depth analysis of the logical issues around cost estimates, a semantic assessment of cost estimates and model development will not be items for discussion in this paper.

3.1. Overview of research methods

The research project is of 4 years duration and involves close analysis of design science methods with the aim of obtaining better standards of work in a digital setting. The project is in four stages; the pinpointing of issues, the putting forward of solutions, the creating of prototypes and the authentication of them. Many different research methodologies have been used, including a review of the relevant literature and professionals being interviewed as part of identifying present problems, with the results available in other papers. As part of the stage involving solution design, standards were reviewed, including data model standards as well as costing domain standards, in addition to interviews taking place to verify the procedures in relation to cost estimates. For the prototype development stage, because of technical restrictions, semantic web ontology will be used to epitomise domain knowledge. In addition, Prolog will be used as a specific reasoning mechanism that uses all the procedures and sections within the reasoned programming setting. The stage of validation involves the use of questionnaires and carrying out half-structured interviews of professional experts so that the results generated can be contrasted with those from the logic programming setting.

3.2. Philosophical stance of cost estimation

The solution espoused has been developed from a particular viewpoint, which is the knowledge aspect of cost estimation. It interprets cost estimation as a vibrant and collective procedure that is based on knowledge and develops as a result of modifications and fresh evidence. Cost estimates are taken as a type of semiosis, or sign-process tasks. The phrase 'semiosis' refers to a process that applies meaning to signs. This approach takes cost estimation as being illustrative of the sign-grounded building of experience models. The human thought process that is used to make decisions involves applying meaning (i.e. items) to signs. The way that the estimator interprets the sign is equivalent to the sway that the sign has.

In relation to the difficulties in determining and quantifying the cost item, illustrative examples are shown below:

Deduction: Rule: If the damp-proof is wider that 300mm, then measure is taken in metres squared;
Sign: Damp-proof >300mm
Object: Unit of measurement is square meter

This modern method of cost estimation suggests three crucial benefits to the procedure: 1) it brings in an authorised BIM-focused cost estimation structure, and includes human reasoning in the estimation process; 2) it improves the chance of information being offered within a context which means estimators are freed from the burden of prioritising particular information; and 3) it makes possible a knowledge-based model of cost estimation. This approach lays the groundwork for a more detailed examination of different kinds of analysis.

3.3. Development trends of computer system

Having closely assessed many different domains, it is the opinion of the authors that the pattern of future systems is going to be geared towards knowledge-based extensions of information systems. Moreover, using BIM technology offers a possible answer to the problem set out earlier through a specific and continuously evolving model during the lifetime of a project [24]. Nonetheless, the BIM model does not have a knowledge perspective at present, so its operation is sub-standard.

In 2012, Hartmann (2012) introduced semiotics in assessing BIM systems. This was done with the intention of developing the communication competence of BIM. The semiotic structure concentrated on technical aspects [26] and, as shown in Liu (2000)'s semiotic ladder in 2000, particularly homed in on the IT stage. It is the author's considered view that the communication issues are because of something intrinsic in relation to the construction industry [28]. Given that the assessment focus on technological issues, it cannot thwart the particular issues arising in the construction business. The main needs are to do with social and structural issues, rather than technical expertise and, as such, how successful a business is in introducing information systems effectively depends on their preparation and planning as opposed to the technicality of the systems themselves [29].

The development of BIM solution must move towards a human-based solution [30]. Indeed, the National Institute of Buidling Sciences (2007) notes that BIM is a computer-generated replica of the actual form of a building. It is therefore a source of information for users to make informed choice in relation to the construction of the building. The authors studied a technological roadmap of BIM that Construction Excellence [31] designed and contend that for the ongoing development of the sector, this needs to be further developed, particularly in relation to AI extended BIM+. It would be helpful to have an AI system that searches through all of the information, spots patterns and unusual aspects, carries out many processes automatically and alerts users to issues that need extra focus. It would also be very useful if AI also pinpointed and clarified possible concerns and gave forecasts using data, so as to give support to the choices that managers make.

This dream of the development of computer systems requires at its heart that computers understand the workflow of professionals. Information has already been provided on the analysis of professional knowledge [32], and this paper instead concentrates on suggested solutions and authenticating results.

4. Proposed Solution

In assessing the context, many aspects to do with BIM-based cost estimation have been studied in detail. It has been suggested that modernised and developed processes could be used which are to do with the ontology used in the construction industry. However, at this point, no research has managed to merge the important aspects in one prototype. Despite many important pieces of research espousing the significance of a semantic underpinning in the domain [33,34], it is recognised that a synopsis is needed setting out all of the different views in relation to a system based on information, which includes compatibility (syntax), a description of pricing analysis (semantics), and precise information about the conditions surrounding the elements being assessed (pragmatics) [35].

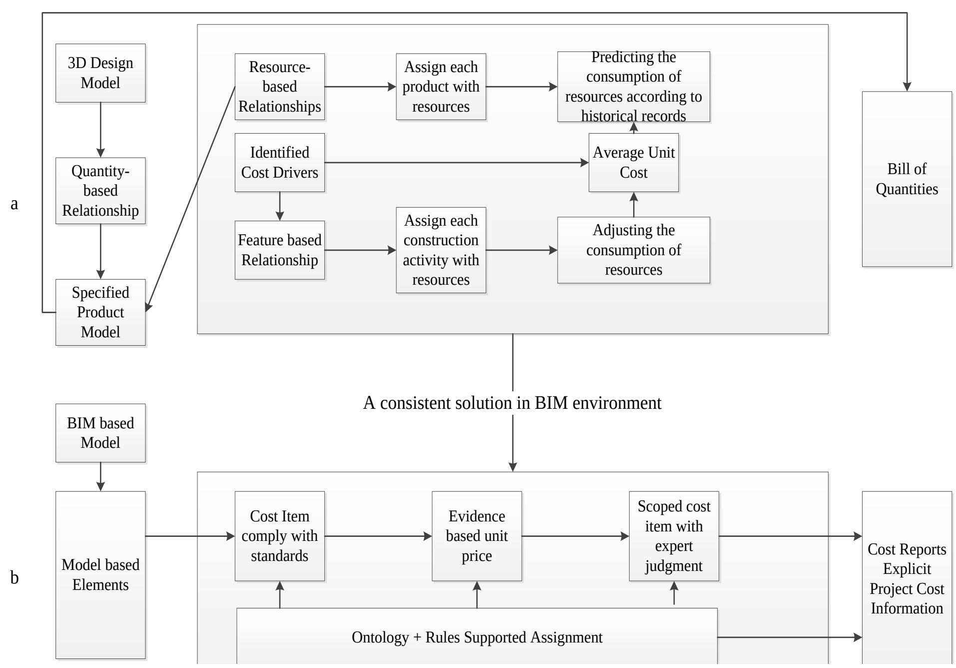

Figure 1 (a) The traditional method of cost estimation via BOQ; (b) The proposed knowledge-based System approach (KACE: Knowledge-based Automatic Cost Estimation)

Figure 1 illustrates the present system of quantity surveying. In designing particular product models for specific construction items, resource-based relationships and feature-based relationships need to be used in cost knowhow. Research indicates that as regards customary techniques of cost estimation, quantity-based relationships may be routinely given to the 3D design model [20].

The most widespread way of producing an accurate cost estimate within reasonable time and at reasonable cost is using the resource-based model. Moreover, activity-based costing can be viewed as an improvement to resource-based relations to ensure greater accuracy in results. Given that quantity-based relationships are straightforward and imprecise, it tends to be left to quantity surveyors to decide the way in which cost information should be amended to maintain equilibrium between the cost estimate and the scale of the project. To allocation an action to each product would require a very detailed model and significant exertion, even though the two models mentioned are still mainly dependent on manual input. To that end, they demonstrate the issues in relation to cost estimation. The first of these is quantity take-off, whereby despite the weighting and cost regulations being altered depending on national and business criteria, there is also significant variation between individuals on this. Secondly, the unit price varies hugely from one quantity surveyor to the next, and a major ambition is to design a constant and adaptable BIM solution [36].

Studying the new measurement systems [21] has allowed the author, in Figure 1b, to offer the notion of an agreed process of cost estimation that could be a reality in a digital environment. Ontology stands for the approach of being ledge focused in this research and the systems followed in this procedure can have an impact on new examples by using current mechanisms. The procedure pinpoints certain aspects and amends the unit cost rate accordingly. Thus, using knowledge from quantity surveyors is another issue that is central to this research exercise. The issue of current practice in terms of knowledge representation in BIM will be covered in the following section. In addition, the organisation issues in terms of using the knowledge from quantity surveyors will also be assessed.

As evidenced by a review of the literature, present BIM cost estimation is a disjointed knowledge process. The IFC model gives information about the building alongside the cost estimation process. The IDM confirms the information passed between the IFC model and the cost estimation and takes quantity off [37]. The IFD then provides the in-depth component knowledge that is within the IFC model but does not simplify the process of cost estimation. Additional improvements are needed from technological developments. A mixed methodology purports that a cost estimate is made using previous information and the project elements, and the cost estimate is then amended by experts to make it more insightful. However, there are variations in BIM-based cost estimations, which is unsatisfactory for industry experts. If knowledge is not integrated into the procedure of cost estimation, it is lost by the process and kept as a result of individual knowledge as to costs. In addition, the procedure can be further sub-divided to be more useful to the carrying out of professional activities by describing, identifying, selecting and amending data during the cost estimation process. Professional work cannot benefit unless a new approach for reviewing cost estimation that takes account of the human aspect, and provides a link between the IT programme and the human role is developed.

5. Prototype and Validation

To use the model so that it could be tested as part of the research, a form of the model was built to give cost estimation information. There were three stages in the development: (1) metadata was taken from code of practice documents, which are connected to cost estimates and laws of measurement [21]; (2) semantic details were recorded; and (3) the procedures were introduced.

Semantic assessment: to achieve the results of the assessment, the Order of Cost Estimation [38] and important processes in relation to cost estimation [39–43] have been assessed. 123 units of metadata have been created as a result.

Semantic data transfer: to achieve the results of the agenda, the semantic aspects used as part of the code of practice, as well as the IFC language, have been logged, as can be seen in Table 2.

Table 1 Semantic units mapping

Documents	Total IFC entity	Number of attributes	Number of relationships
Order of Cost Estimation	22	27	8
Bill of Quantities	42	59	22

Table 2 Result of comparison (Brick Wall)

Components	Traditional method						Proposed method
	A (4 years)	B (8 years)	C (2 years)	D (12 years)	E (6 years)	F (10 years)	
Cost Item Description*	A,B,C,D	A,B	A,B,C	A,B,C,D	A, B, C, D	A, B, C, D	A,B,C,D
Measured Quantity	$12.46m^2$	$11.43m^2$	$12.46m^2$	$12.46\ m^2$	$12.46\ m^2$	$12.46\ m^2$	$12.46m^2$
Material Unit Cost	$4.66\$/m^2$	$49.72\$/m^2$	$4.56\$/m^2$	$6\ \$/m^2$	$4.66\$/m^2$	$4.56\$/m^2$	$4.56\$/m^2$
Labour Unit Cost	$3\$/m^2$	$33.71\$/m^2$	$3.18\$/m^2$	$4\ \$/m^2$	$3.17\$/m^2$	$3.17\$/m^2$	$3.17\$/m^2$
Adjust on Labour Unit Cost	0	0	Increase 20%	0	0	Decrease 20%	Decrease 30%
Scoped Labour Unit Cost	$3\$/m^2$	$33.71\$/m^2$	$3.82\$/m^2$	$4\ \$/m^2$	$3.17\$/m^2$	$2.54\$/m^2$	$2.22\$/m^2$
Total	$95.44	$953.60	$104.41	$124.46	$97.56	$88.47	$ 84.48

***Note: A: Material, B: Working Methods, C: Size, D: Location, E: Additions**

The results depicted in Table 3 are limited due to constraints of space, but they illustrate the contrast between results from specialist analysis and those of KACE with three different cost items. Expert A pointed out that the accuracy of brick wall estimates would be better if drawings of rebar and concrete beams were added as they could be utilised to strengthen the force of the wall. It would be a useful discussion to consider how these points could be used as part of the knowledge base or in the IFC model but it is beyond the scope of this research. Expert B noted there was insufficient information about tiles and extra quotations were needed. They also did not notice the boundary works had been included and, in the feedback, they agreed it needed to be included and the unit cost could be calculated from the information given. Expert C noted that the height of the brick wall might mean that productivity may reduce by 20% which would cause increased labour unit costs of 20%. Expert D gave the unit cost of brick based on his experience because of the shortage of drawings of rebar and concrete beams for brick walls.

From the different assessments given, KACE shows that expert analysis and knowledge of analytical cost estimation can be measured and leads to similar cost items as experts calculating it on their own. The variation between totals emphasises how vital it is to record and automate the procedure.

6. Limitations

Looking more broadly, the approach being suggested and its semantic, practical and standard and it would apply to other areas of construction, for instance, checking the energy performance of buildings, checking for collision, and BIM-based construction management. It is possible to use ontology and rules to computerise the knowledge works of professionals and to build reasoning models of the knowledge. Nevertheless, there is little agreement on how useful such mechanisms would be. In addition, it is unknown what the construction of social knowledge trends would look like, or how a special example of a knowledge model would vary from that ‘ideal’ state.

Looking ahead, research should aim at establishing a more in-depth appreciation of the BIM-based construction management. The discussion on the theory of working designs involves several related areas, from the role of artificial intelligence, to how procedures, models and data are seen. Nevertheless, applying this approach can make the gathering of information more straightforward and give it a context which will assist in introducing models for large amounts of data.

7. Conclusions

It believes that BIM is a procedure which uses object-focused models to design a building in addition to giving design information to all of those involved. The procedure involves using computerised data to take away the limitations of the construction sector. BIM methods should be assessed as a transporter of particular data that needs to be subject to further examination from construction experts. As noted by . Eastman et al. (2011), the primary focus should be on organisation rather than technical prowess.

The purpose behind the research was to design a method for automatic cost estimating based on BIM to offer an AI assisted professional workflow. A fresh method of using a KBS in a BIM setting can be put forward. Domain ontology can be engaged to encapsulate the semantics of the costing process and a business process modelling with norms can be used to measure the application logic (professional problem-solving procedure). In addition, an analysis on professional problem-solving methods and domain ontology in a reasoning technological setting can offer a connected approach to cost estimation.

Analysis supports the methodology of automatic cost estimation as being appropriate, and for BIM-based cost estimation to be extended to a knowledge viewpoint. The end target of the research is to put forward a philosophical viewpoint in terms of professional work, so that it is not only restricted to cost estimation but more broadly in the analytical procedure. To that end, another paper has been published that deals with healthcare analytics processes [45]. It should also be noted that no technical information has been given here because of the limitations of space, although it is the intention of the authors to publish detailed tech specification in Automation in Construction.

It needs to be observed that the addition of extra metadata and uses the clauses is at present done manually, and there is the potential for this to be done electronically. However, with increased confidence in automated systems, the expectation is that codes of practice will be carried out in a semantically targeted fashion which allow the links between items to have clarity. This amendment in how codes of practice are presented will mean that they are made in ways that allow them to be made automatically, with human comprehension being something that comes out of the system, rather than being involved in the input. This method of succeeding in having automated regulation checking procedures was supported by Beach et al. (2015).

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Automation for building performance and maintenance efficiency

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Abstract

In Western Europe, 80% of buildings will continue to exist beyond 2050. Almost all, 98-99%, need to be updated and maintained in conformity with the requirements to new buildings, designated as nearly zero-energy buildings (nZEBs). In principle, buildings with modern superstructures have a potential lifespan of over 120 years, without compromising safety. Considering materials, labor, logistics, pollution, gas emissions, energy involved in the construction and assuming its heritage value, it is recommended a full modernization of buildings to assure their utility in favor of communities. This research focuses on reaching the maintenance efficiency and buildings performance, without increasing the costs.
The Model is designed to measure and anticipate the degradation of buildings, in three steps. Starting with a network of active sensors, embedded and non-embedded in layers of components and subcomponents, which survey and monitor the condition of the building systems. Those will provide accurate data for computational analysis (first step) and quantify and qualify the viability of construction systems with the highest impact on building performance. The information supports the managers' decisions (second step), before compromising the materials and the constructive solutions, saving work time, reducing maintenance costs, and assuring the highest performance, while preserving user's comfort. And promote a rapid and specific response to stop early anomalies (third step), by obtaining an outsourced contract to respond to daily basis needs (and not tasks) with specialized technicians.
The information collected will help to determine policies, anticipate anomalies, plan proper maintenance, ranking investments and intervene on marked systems. The three-step model aims for a reduction of natural resources usage, a decrease of human impact, to increase the efficiency and to improve the performance of the building stock.

Keywords: autonomous building maintenance; computational maintenance model; facility management; building maintenance sensors; building performance; building user experience; energy efficiency in building

1. Introduction

The research aims to design a three-step maintenance model to improve building usage on a low-cost basis; by understanding the contribution of surveying buildings systems to slow the aging and degradation processes. To apply nZEBs concept of the building stock, based on a network of active sensors to measure the condition of passive systems. And support renovation for those compromised through the best contemporary materials, and cutting-edge building solutions, gathering comfort, efficiency, and more straightforward maintenance; all in favor of the managers' decisions, Facility (FM) and (or) Property (PM).

In Western Europe, 80% of buildings will continue to exist beyond 2050. Almost all, 98-99%, need to be updated and maintained in conformity to the requirements for new buildings, designated as nearly zero-energy buildings (nZEBs). The European Union aims to reduce 80 to 95% carbon dioxide (CO_2) emissions from the construction sector [1]. Therefore, the definition of strategic guidelines is essential to ensure, foreseen, higher energy necessities, and the development of cleaner energy sources: locally produced, manageable by consumers, and inexpensive (when compared to fuel fossil standards).

Since 1980 many existing buildings adopted passive solar design, and Passive House (PH) concept to gather higher efficiency by lowering the energy consumption, from 70% to 90% or 15kW/m^2.year. More would be possible,

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assuming today's knowledge and technologies, but due to players conservatism, new approaches were unconsidered, especially when the new is more expensive and unproven. Nevertheless, when applied to buildings, savings of 65% to 90% can be achieved, if efficient acclimatization is used, comparing the initial consumptions to the renovated [2].

Nowadays, the European Union (EU) is one of the driving forces in the pursuit of the reduction of CO_2 emissions. Europe, a stable Continent since World War II, has a vast building stock with high architectural value, which deserves to be properly maintained and updated to meet future policies, considering current environmental concerns. To accomplish this goal, the EU established an observatory, ZEBRA2020, responsible for promoting and surveying the implementation of nZEBs (nearly zero-energy buildings). However, its efforts are directed to new buildings.

In EU countries, 40% of the buildings were built before 1960 and 90% before 1990 [3], consuming 40% of the available energy (55% as electricity) and emitting 36% of CO_2.

The PH approach is being used to increase building efficiency, to comply with the Paris Agreement (PA) guidelines, and ensure that 2°C above pre-industrial levels are not exceeded. To accomplish this goal, EU intends to reduce 40% of CO_2 by 2030, when compared to 1990 values; 1/3 of the effort must be made by buildings renovation [4].

1.1. *Question*

In the EU, new building construction to replace existing ones is around 1% per year, considering all stock. The new buildings' market is lethargic, creating the opportunity for renovation, to meet the PA goals.[1] Those operations represent 57% of the Sector's revenue, but only 1 to 2% of existing buildings improve the energy efficiency as established for new buildings [4]. By 2020, it is intended to grow the renovation up to 2-3% (the highest percentage considers public buildings), improving to 20% the building stock energy efficiency, and 27% by 2030.[2]

Past construction technology tends to be less energy efficient when compared to the newer: meaning higher energy consumption and therefore more CO_2 emissions [5]. Nevertheless, not all of the existing buildings have the same renovation potential to achieve the required efficiency, depending on its owner's usage intentions and financial capacity, construction potential, and architecture nobility [6]. The investment versus reimbursements, based on potential gains — energy reductions, and maintenance, life cycles and lifespan — are achievable in less than 30 years [7].

Construction on developed countries, as a fundamental need, is continuously surveyed, analyzed and improved to meet high-quality life standards. The American and Western Europe market represent 53% of all efficiency investments. For the US, the Sector projected expenditures from US$ 7.4 trillion in 2010 to US$ 8.5 trillion in 2015 and US$ 10.3 trillion in 2020, at 2010 constant prices and exchange rates [8]. A recent survey (2015-2017)[3] shows that the Sector is highly committed to efficiency efforts in 'building designs and construction' and 'building operations and maintenance': 77% responded 'very highly preferred' and 70% 'highly preferred', respectively; and, also, the industry's transparency in pursuing the buildings' efficiency, 48% of the surveyed pointed out a growth of 10% for next 12 months (2015-2016). But the Industry also recognized its 'higher initial cost' as assumed per 69% of respondents (2015). In the European Union (EU), the Industry contributed to 9% (EUR 13 trillion) for the Gross Domestic Product (GDP), ensuring 10,46% (18 million) of total available jobs. While it ensures the economic growth, the cut of CO_2 emissions, as it moves away from the fuel fossils [9]. The renovation market in the EU, in 2015, was worth approximately EUR 109 billion, assuring 882,900 jobs; it is, at least, questionable not to invest in building stocks' maintenance by applying the latest technologies, most produced locally.

The construction industry plays a significant role in the global economy, however it is one of the most resilient to adopt cutting-edge technology, in both construction and maintenance. In spite of that, automation is emerging in new buildings, and high-quality renovations; both enforcing measures to control energy (e.g., lighting, HVAC, ventilation, plumbing and conveying).

1.2. *Background*

Industries turn to technology, by investing and researching solutions, when the lack of safety and maintenance become public issues. While, 'active' surveillance can play an important role in diminishing questions raised by current

[1] The Energy Efficiency Directive (EED) (2012/27/EU) defines building stock as "the single biggest potential sector for energy savings... crucial to achieving the Union objective of reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990."
[2] On October 27, 2017, the European Commission announced the allocation of €30 billion on the Horizon 2020, a European Union research and innovation funding program, between 2018-2020, including €2.7 billion to establish a European Innovation Council.
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requirements (on PA perspective) for energy efficiency on the building stock; addressed by recent technology to solve issues, as a standard approach since the World War II.

"ENERGY STAR" and "Leadership in Energy and Environmental Design" (LEED) were developed, more than two decades ago, as tools to measure energy efficiency and sustainability. Instantly, gathering much public interest which promoted to the green movement. New solutions have been implemented by professionals, designers and operators, to accommodate the consumers' needs and label buildings according with their ecological footprint.

Today, some automation systems are available, offering immediate adjustment to the maintenance schedule, but limited to powered equipment. The goals are: systems' efficiency, decrease of energy consumption, costs reduction related to operations and activities, improvement of equipment efficiency and infrastructure life-cycle.

Two systems are frequently used by the Sector: Building Automation System (BAS), embodies the control and management of heating, ventilation and air conditioning, lighting and others, and Building Management Systems (BMS), with a more extensive automatic surveillance, managing BAS and gather other systems, like water supply, security and fire control [10]. BMS are adaptable to different buildings scales and functions, managed by a single workstation or by an operations center, but they need a dedicated network plus software, to minimize tasks and complexity for chief engineers and building operators. However, BMS/BAS tend to be expensive when compared to other systems, and don't gather analytic insight, relying on facility manager's judgment and decisions. Systems based on electric infrastructure, as Energy Management Software (EMS), are easier to install and operate, affordable when alongside BMS/BAS and opened to third parts' resources, gathering outside conditions (wind speed, temperatures, humidity, pollution, et cetera) on time, sharing information with nearby buildings; and, adapting to the weather forecast. The EMS is adjustable to different building scales and institution needs and can work alongside BMS/BAS, increasing overall savings, and optimizing operations.

The TechNavio forecast to improve active systems' efficiency, in June 2017, by the buildings' automation will grow, by 2021: above 9% on software; and 11% on control systems, based on wireless sensors. [11] Automation is a trend, and the Sector shows a propensity for its use on future products, but its significant impact depends on the building stock managers decisions.

Nowadays, buildings maintenance's researchers subscribe to the need of computational support to segregate the information workflow, showing the viability of systems regarding the condition, the life-cycles, and the lifespan [12][13][14][15][16]. Still, those limited to energy consumption on active systems. The passive systems energy losses are neglected: not attending real performance condition or upgrades towards nZEBs directives (as intended for the EU new buildings).

Building Information Modeling (BIM) researchers support the introduction of Information Technology (IT) in the "architectural, engineering, construction and owned-operation" (AECO) industry to increase energy efficiency, productivity, and profitability [17][18]. Nevertheless, the quoted only supports the improvements on new building operations and, as disclosed above, built in urban areas in developed countries, taking into consideration the population growth or a new economic paradigm.

At present, the focus of the industry is to produce buildings with greater energy efficiency, overseeing equipment such as HVAC [19] [20], lighting [21] and energy consumption management [22] [23].

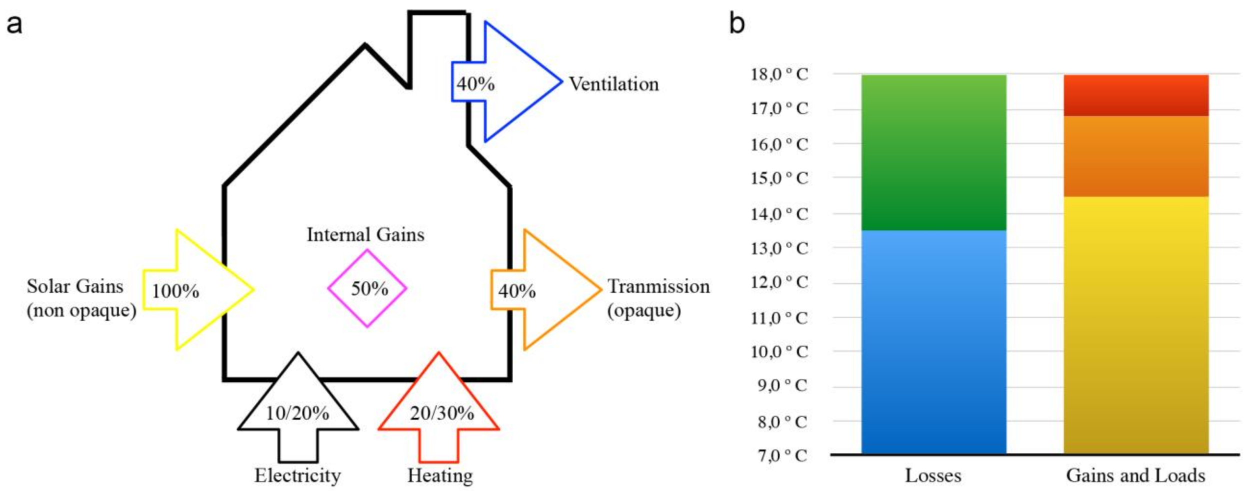
Today, the focus of the industry is to produce buildings with greater energy efficiency, by overseeing the equipment, such as HVAC [19][20], lighting [21] and energy consumption management [22][23]. Nevertheless, active systems are responsible for less energy consumption (kWh/(m^2.annual)) when compared to passive's, according to data provided by Fachinstitut Gebäude-Klima e.V., 2007 [24].

Building external enclosure allows potential energy losses and requires high maintenance (various finishes over multiple layers). The thermal performance can be improved if a correct technological approach is considered; by addressing, e.g., the shortcomings/insufficiencies of the insulation, humidity presence, and the air permeability through finishing and layering systems [25]. When simple sum with active systems, passive systems have a broader spectrum on constructive solutions, of different designs style, shapes and materials and layering composition, and can be responsible for a significant reduction of energy consumption, up to 50%. At the same time, when combined they can achieve a reduction of energy consumption up to 60%: e.g., strategies for heating or cooling in line with external enclosure performance. [26]

Buildings lifespan is often divided in the three major phases: design, construction and operation [27]. Maintenance works cannot end, otherwise, the buildings' performance and their operations get compromised. To control the aging and external factors it is essential to maintain a close surveillance, and IT can play an important role, alerting to the compromised systems' performance. Although, today, they are limited to design and construction phases [28][29]. To perceive the energy efficiency, the focus must be on higher costs [30] and with the environmental impact [31] along the operation phase, mainly on maintenance contributions.

1.3. Possible Approach

The standard maintenance plans, imposed by law, are produced by the designers gathering technical information shared by developers and suppliers of materials, constructive solutions, and power equipment, to be provided to owners and investors to manage the buildings during the first decade;. During the buildings' warranty period, FMs and PMs technicians monitor the systems' condition. Nevertheless, the condition evaluation depends on the technical skills and experience of the technicians. For a correct perception, it is advisable to resort to three technicians (at minimum) to reach the true condition's analysis. Such number of technicians represent a high cost for institutions, and are difficult to justify, especially when there is an excellent global condition perception. Also, the reported data is exposed to externalities such as interpretation, communication, coordination, and achievement. Managers will consider the anomalies report, and repair costs; a decision will depend on several issues: e.g., assurance, awareness, financial capacity, and investment priorities, to react before future expenses. The high maintenance costs are, potentially, linked to under-evaluations, resulting in future complex tasks, but the over-evaluation also diminishes systems life expectancy



by neglecting minor repairs.

Figure 1 - (a) Regenerative percentage of the heat recovery [9]; (b) Average EU Heat balance for space heating 2010 (VHK 2014) [32].

As shown and pursued by this research, a wide a range of active sensors can contribute to maintain building stocks at the highest level of performance, as demanded by the PA: in high energy efficiency, low-cost maintenance, with a spaced schedule and less demanding. The System intends to survey a specific building aging by analyzing and comparing it to others. So, maintenance is adjusted with third party contributions (anomalies' reports and solution tasks), working with a global network; the external database will define the optimization models and the best approach.

Buildings depend on vital systems to assure usability, comfort and performing without compromising the overall efficiency; as described on "Facilities Maintenance Management Model," by Igal M. Sohet and Sarel Lavy, marginal condition (above safety) 80%. Building systems are complex and deeply connected, and to monitor them it is mandatory to resort to a spectrum of sensors and related technology, gather by Internal Systems (communication tools, hardware, software, and databases) and External Systems (defining ideal models). These tools already exist and are commonly applied, in other industrial products, assuring precise maintenance and high-performance during all lifespan.

1.4. Manuscript Structure

This manuscript presents an overlay monitoring system to increase the performance of the buildings' stock in developed countries. The possibility of assessing the condition of the passive system, during the building's lifespan, shows the importance of envolving IT and AI in the future of building maintenance; by preventing, reacting and reducing the impact of degradation. The effect of the running costs to property owners, in energy and maintenance expenditure, is, also, overseen. In the end, it is presented the research results and discussion of the introduced systems, as a significant contribution to achieve the Paris Agreement goals, driven by the nZEB concept. As a conclusion, focusing on the building life experience to reach the highest performance possible, at the same time, ensuring the lowest servicing costs.

2. Methodology

2.1. Maintenance Adviser System (MAS) and Automatic Maintenance Surveillance (AMS) Design

The Maintenance Adviser System (MAS) and Automatic Maintenance Surveillance (AMS) are two mechanisms that work side-by-side to improve building stock renovation. MAS is a master server that confirms AMS outcomes, in order to provide intelligence renovation advise to property management teams, as exposed in Figure 2:

1) Surveillance Network;
2) Sharing Data (MAS between AMS);
3) External Contributions;
4) Measured Condition;
5) Visual Inspection and Testing Equipment by FM personnel and, if assurable by in-house capacity, underwork (Final Stage I); If not,
6) Reported Under Performance System Condition;
7) Delayed, if not accepted;
8) Acquisition process, is accepted;
9) Outsource Contract; and,
10) Underwork (Final Stage II).

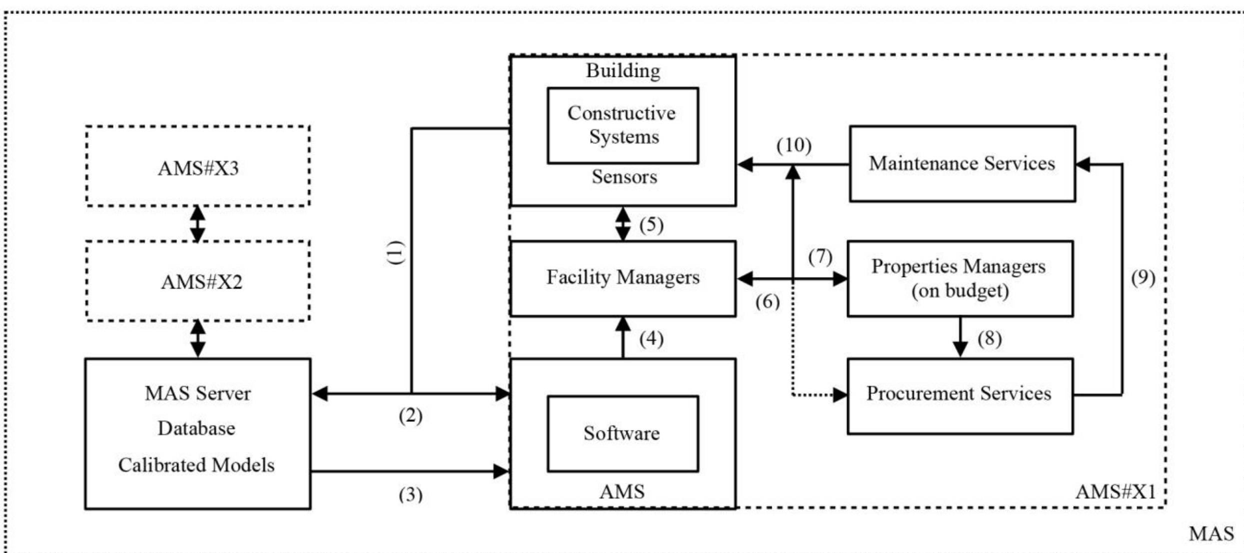


Fig. 2. Maintenance Adviser System (MAS) and Automatic Maintenance Surveillance (AMS)

Any existing building will share its technical systems with others, with similar characteristics. And, if that connects to a local surveillance system, it is possible to compile data and measure aging and other external contribution rates. Building systems will need to be categorized taking into consideration building's systems characteristics. In order to be monitored, a building requires the installation of a wireless sensors network, connected to local WI-FI, to survey its condition and allow AMS' processing, compiling data shared with the Global Automatic Surveillance Advisor System (MAS) to certify the collected info.

The MAS system collects renovation data, on similar building stocks, and monitors their performance on-site, to support future advise on similar needs (AMS#X1/X2/X3…). Performance has, on both systems, multidimensional importance in ensuring the renovation's quality and strength, even in low-cost maintenance and with spaced cycles, as it guarantees the increase of energy efficiency towards nZEBs. To achieve an in-depth renovation, it is mandatory to fulfill a few milestones as standard high-technology, at reasonable prices, and resort to tested solutions. All in performance favor based on lowest investment and reimbursement on the shortest period.

The AMS action depends on a sensor to read and detect an anomaly and to report it to the external server (1); confirmed by calibrated models (2); and redirected to the AMS server (3). The facility manager's team will receive a report (4) that requires confirmation on-site (5), if favorable, it will be submitted to the property's managers (6/7), after accepted is transferred to procurement services (8). These services will be acquired externally or demanded to the internal maintenance team (9) to proceed with the renovation repairs (10). As above written, the achieved renovation tasks and the further monitoring will feed MAS, which will provide valuable information to address similar anomalies in building systems.

2.2. *Sensor Network on Passive Building Systems*

Sensors play a fundamental role in the systems, therefore, must be based on standard technology to maintain a low-price tag. Since they obtain the condition of passive building systems, it only implies a data input per day to feed AMS. If a system gets compromised, the sensor should alert the property managers and offer pre-uploaded solutions, based on MAS. These solutions derive from other renovations on similar buildings and, more important, they are monitored accordingly with their performance through time. The procurement procedures and the team responsible for the renovation works must be registered (for future consulting), assuring the best results on the forthcoming renovations.[4]

3. Results and Discussion

In developed countries, it is difficult to demolish an old building, especially, in the urban environment, without a significant impact on the cities daily life, its users, and businesses. Cities are densely structured, and construction works are expensive and time-consuming, emitting light particles, producing gas emissions, consuming essential resources with impact on urban dynamics, by affecting mobility and overload the supply grids: despite the pursuit for debris recycling [33]. Massive works in confined blocks, surrounded by others, raise potential risks for workers and properties. None the less, there is a tendency for demolishing buildings before exploring all their potentialities [33].

Maintenance embraces the idea of renovation by over-laying increasingly, adding or changing the existing building systems. Other forms of maintenance, like conservation, tend to diminish through the system's lifespan (along with its viability), and rehabilitation will eventually vanish from the Sector. Conservation is profitable in the early stages, but renovation is so dependent on the workforce and time-consuming that, at some point, will be deferred in favor of major construction works.

This research intends to increase the performance and lifespan of today's buildings, by monitoring the passive systems aim and their contribution to the overall efficiency. By adding them to the efforts achieved on the active systems' monitoring, as BMS/BAS and EMS, nowadays [10]. In opposition to those, AMS sensors are designed to communicate directly with the WI-FI network and its hardware/software, in-house [11], and, on a higher level, to cross information with external data systems, like MAS, to read, analyze, and react, based on the performance of similar renovation operations.

BIM's aim for a universal approach to buildings' design and management, but, as established today, fail to spread into existing buildings. Further steps are needed so that BIM will be able to oversee passive systems performance, as aging rate and external impacts on their lifespan. They should work side-by-side with active systems maintenance, ensuring the same care, once both contribute to higher energy consumption, when not properly maintained [17][18]. When passive constructive solutions reach an underperformance condition, the energy consumption increases: with a higher impact on overall costs, demanding a more effort from actives'. The firsts have an extraordinary effect on the user's comfort, therefore, must be on the focus of the PMs teams. [24][25][26]

[4] The sensors technological approach will be developed in a future paper.

Building Maintenance Automation is a tool to identify and prevent early stage anomalies while is self-learning from similar conditions; it will benefit properties development and their activities, avoiding downtime and underperformance. All supported by precise data, in real-time, on building systems aging condition: to avoid high energy consumption and reduce building performance or the uncertainty on maintenance expenditures. At the same time, ensuring the maximum outcome, aligning building's lifespan with maximum performance, as driven by environmental goals.

4. Conclusions

Building degradation starts on day one. Maintenance can slow down the rate of overall performance lost. Conservation, in the first years, and rehabilitation, later, can maintain a building's condition close to the original. Due to evolution, the systems will get outdated, when considering to the present goals. The solution is renovation through the latest building achievements, especially in energy savings. Aimed by the Sector: the automatic renovation of the building systems when under-performing or near the end of their life-cycle.

The Automatic Maintenance Surveillance can help property owners to reach savings, by applying monitoring systems on passive systems and proceeding to 'smart' renovation based on high-tech materials and building solutions tested (available on local markets), and, also, evaluated by the AMS, in previous improvements on similar buildings.

The automation applied to maintenance, on condition monitoring and reparation advisor, fed by a set of digital sensors, embedded and non-embedded in building systems, surveying existent building condition, collecting information to pursue today's energy efficiency goal, can reach the nearly zero-energy buildings (nZEBs) concept. This goal will create a new market share, with a high potential for growth, in maintenance expenditures and activities. In years to come, especially in the most requested properties or with a high economic value, it can translate into an extra revenue to institutions, while it meets the PA guidelines.

The evolution of building maintenance will be assumed by artificial intelligence, as presented above (MAS+AMS). Systems will self-learn if provided with the income directives and policies for buildings maintenance and the new materials and buildings solutions available, assuming the best maintenance decisions aligned with the policy goals.

Maintenance Systems, as MAS+AMS, will get more precise by integrating the incoming building solution characteristics and crossing them with the building stock. They will be able to perceive the scopus of renovation, and after a renovated solution is applied, it will keep on monitoring those performances to be considered on other building stock. Nonetheless, with the collected data is possible to foresee the behavior of those new solutions, in conservation cycles, costs and lifespan.

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Automation of Davidovits theory in construction using mobile laser robot

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Abstract

The truth behind the approach of building the Giza pyramids (Egypt) is still unknown. Many postulates were proposed. Noted in the past years the theory of Professor Joseph Davidovits indicating that the pyramids were "assembled" in place by heating the mud. This was proven by the identified amount of water found in the test of the nanoparticles. The advantage of such approach is bypassing the mobility and weight issues of the stones. In this paper we offer a simulation of the construction process using a multipurpose robotic manipulators. The role of this mechanism is to inject mud and heat it using LASER technology.

Keywords: Automation of construction processes, modeling mobile robot, robot control, Davidovits theory ;

1. Introduction

Construction is one of the aspects of social development. Evolution of the construction concepts and arts depends of the needs and prosperity of the society. Historically, human was relying on hunting for day-to-day living. The cave was enough to protect him from climatic conditions and risks. Acquired the knowledge of agriculture, human had to store goods and products in permanent settlements: tents were set up from animal bones and wood, huts from leaves.

In Mesopotamian period, clay, plain and glazed bricks were introduced in Chaldea. While Assyrians used bricks and stones, the Persians preferred limestone and timber to build their communal houses. The Egyptians continue the tradition of using natural products and masonry materials (basalt, granite, limestone). Greek used the marble, while their successor the Romans used concrete, which continued as primary building materials until the industrial age introducing steel and glass. With the development in nanotechnologies, engineers aim to achieve the hitherto difficult invention of long lasting [pp.158, 4; pp.66, 5], light (transportation) [pp.7, 6], and flexible building materials [pp. 57, 2; pp.80, 3].

The result appears in the 3D printing technology. These printers can create products starting from pens, guns or biological organs. With relation to construction, China is set to build in Dubai the first 3D office covering an area of 186 square meters using 6-meter tall printer. Already China is specializing in printing large buildings achieving recently 6-strory apartments occupying 1100 square meter area. It is estimated that a single house can be concrete printed in less then one day.

2. Mathematical model for laser glazing robot

In this paragraph, we will be describing the glazer robot, identify it mathematical model and control approach. The robot consists of two major parts, the CO_2 Laser generator lifted by a mobile cart. The generator part has 2 water-cooled electrodes between them high frequency stimulating the laser gas. Alongside with couples of mirrors, the two electrodes form the resonator. A concept of the CO_2 laser machine is illustrated in fig.1 [pp.18; 9].

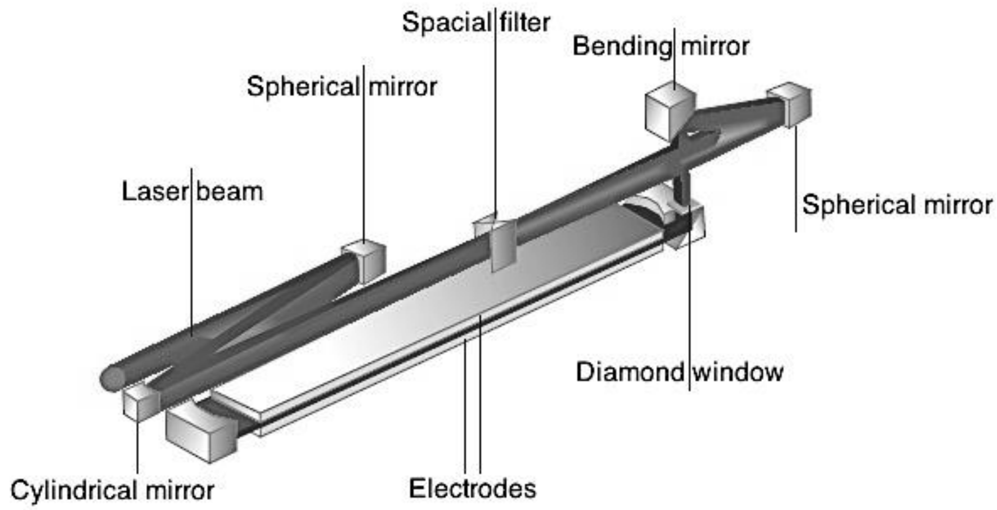

Fig.1. Concept of CO_2 laser machine

We aim to perform slab and walls concrete treatment. Hence the laser should reach different altitudes and corners. We can consider the cart and the lifting mechanism as a possible simulation for our case study. Therefore we will represent the setup as two-dimensional problem of an inverted pendulum moving in the vertical plane as shown in the fig.2. bellow. While the cart is moving, it applies force F on the lifting mechanism, which in its turn will tilt around the fixation point by an angle θ. Hence the control input is the force F and the control output is the angle θ and the horizontal movement of the cart x [pp.5 ,11; pp.25, 12].

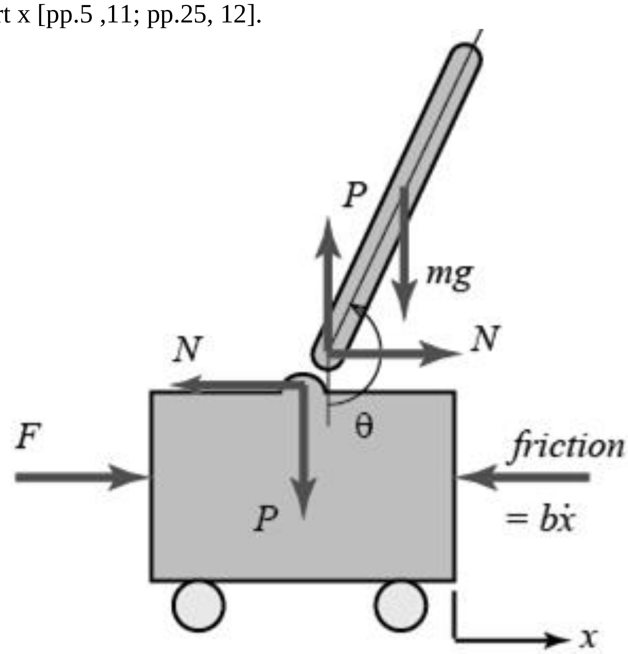

Fig.2. Two-dimensional inverted pendulum problem

In fig.7 are marked the forces applied to the body frame. Using Newton law of motion we can introduce the sum of the forces in the free-body diagram of the cart and pendulum in the horizontal direction:

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$$M\ddot{x} + b\dot{x} + N = F; \tag{1}$$

$$N = m\ddot{x} + ml\ddot{\theta}cos\theta - ml\dot{\theta}^2 sin\theta; \tag{2}$$

where M and m are the mass of the cart and the lifting mechanism respectively; b is the coefficient of friction depending on the wheels and the floor type.
Substituting equation (2) in (1) we obtain the following equation

$$(M + m)\ddot{x} + b\dot{x} + ml\ddot{\theta}cos\theta - ml\dot{\theta}^2 sin\theta = F; \tag{3}$$

Summing the force perpendicular to the pendulum we get the second equation of motion

$$Psin\theta + Ncos\theta - mg\sin\theta = ml\ddot{\theta} + m\ddot{x}cos\theta; \tag{4}$$

The terms of P and N can be found be summing the moments about the centroid of the pendulum. Hence we can write:

$$-Plsin\theta - NlPcos\theta = I\ddot{\theta}; \tag{5}$$

Combining equation (4) and (5) we obtain the second governing equation

$$(I + ml)\ddot{\theta} + mglsin\theta = -ml\ddot{x}cos\theta; \tag{6}$$

Using the trigonometry low of small angles, equation (3) and (6) can be written in the following simplified forms

$$(M + m)\ddot{x} + b\dot{x} + ml\ddot{\Phi} = u; \tag{7}$$

$$(I + ml)\ddot{\Phi} + mglsin\Phi = -ml\ddot{x}; \tag{8}$$

Using u and Φ where replace the F value and small angle terms hereafter.

The next step consists in finding the transfer functions of the system. Therefore we need to introduce the Laplace transformation of the equations assuming zero initial conditions. The equations (7) and (8) can be written as follows

$$(M + m)X(p)p^2 + bX(p) + ml\ddot{\Phi}(p)p^2 = u(p); \tag{9}$$

$$(I + ml)\ddot{\Phi}(p)p^2 + mglsin\Phi(\text{p}) = -mlX(p)p^2; \tag{10}$$

where p is the Laplace operator.

Taking into consideration that the transfer function is the relation between the form of single input and single output at one time and rearranging equations (7) and (8) using linearization method we obtain the following:

$$\frac{\Phi(\text{p})}{u(p)} = \frac{\frac{ml}{K}p^2}{p^4 + \frac{b(I + ml^2)}{K}p^3 - \frac{(M + m)mgl}{K}p^2 - \frac{bmgl}{K}p}; \tag{11}$$

where $K = [(M + m)(I + ml^2) - (ml^2)]$; and $W(p) = \frac{\Phi(\text{p})}{u(p)}$.

From the transfer function above we can clearly see that there is a pole and zero at the origin. Hence the transfer function can be rewritten using the following system of equations:

$$\frac{\Phi(\mathrm{p})}{u(p)} = \frac{\frac{ml}{K}p}{p^3 + \frac{b(I+ml^2)}{K}p^2 - \frac{(M+m)mgl}{K}p - \frac{bmgl}{K}}; \tag{12}$$

$$\frac{\mathrm{X}(\mathrm{p})}{u(p)} = \frac{\frac{(I+ml^2)p^2 - gml}{K}}{p^4 + \frac{b(I+ml^2)}{K}p^3 - \frac{(M+m)mgl}{K}p^2 - \frac{bmgl}{K}p}; \tag{13}$$

where $\frac{\Phi(\mathrm{p})}{u(p)}$ and $\frac{\mathrm{X}(\mathrm{p})}{u(p)}$ are the pendulum and cart transfer function respectively.

The whole system can be represented in matrix form using state space equation. Hence we can write the following:

$$\begin{bmatrix} \dot{x} \\ \ddot{x} \\ \dot{\theta} \\ \ddot{\theta} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & q_1 & q_2 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & q_3 & q_4 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \theta \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ q_5 \\ 0 \\ q_6 \end{bmatrix}; \tag{14}$$

where

$$q_1 = \frac{-(I+ml^2)b}{I(M+m)+Ml^2};$$
$$q_2 = \frac{m^2gl^2}{I(M+m)+Ml^2};$$
$$q_3 = \frac{-mlb}{I(M+m)+Ml^2};$$
$$q_4 = \frac{mgl(M+m)}{I(M+m)+Ml^2};$$
$$q_5 = \frac{I+ml^2}{I(M+m)+Ml^2};$$
$$q_6 = \frac{ml}{I(M+m)+Ml^2}.$$

The output of the system Y can be represented using the following equation

$$Y = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ \dot{x} \\ \theta \\ \dot{\theta} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix} u; \tag{15}$$

The matrix $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$ has two rows representing the cart position and the pendulum movement.

For us, the most important is to control the movement of the pendulum as it represents the lifting effect and movement of the CO_2 laser beam. But still the cart has to reach the indicated area.

The figures 3 and 4 represent the simulation results of resolving two-dimensional inverted pendulum control problem. Figure 3 illustrates the horizontal movement of the cart as consequence to tracking force F. As it is seen the cart moved linearly smoothly.

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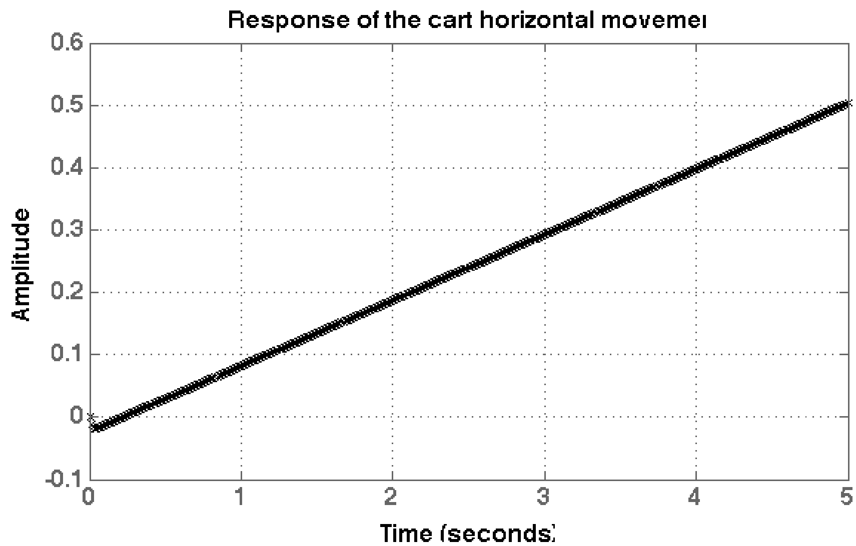

Fig.3. Cart movement from zero initial condition

On the other hand and following a sudden movement of the cart, the lifting mechanism curve has shown an overshoot then the working angle was stabilized.

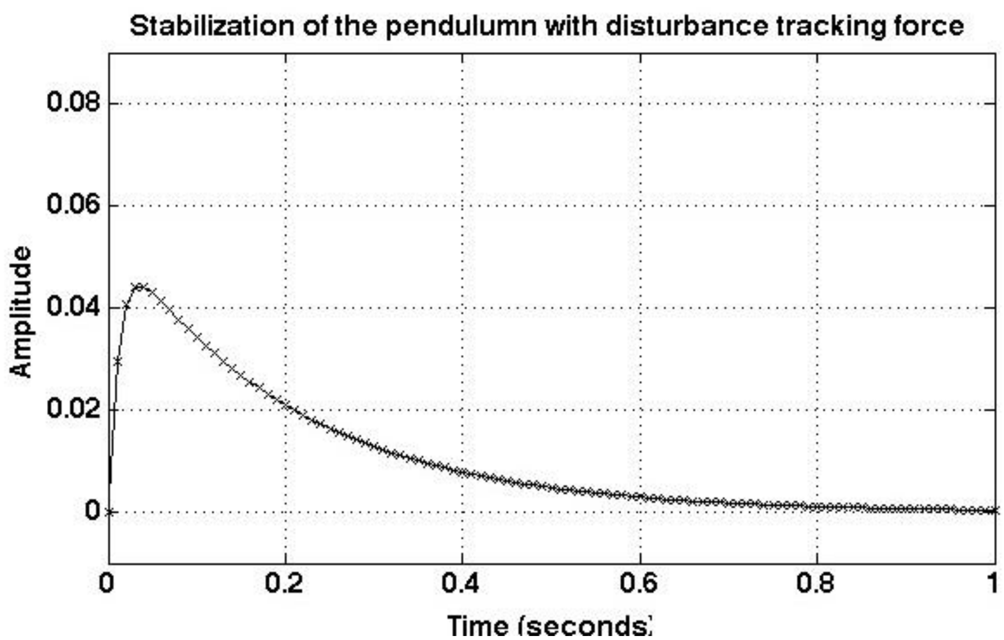

Fig.4. Lifting mechanism stabilization to desired position while the cart is moving

The successful control of the inverted pendulum consists of stabilizing the lifting mechanism while the cart is moving smoothly in the horizontal plan. Hence by implementing the control approach the shape of the curve representing (X) should be ascending, while the rotation of the pendulum (θ) should be consistent to a pre-assigned value representing the working angle or the reaching of the laser beam [pp.3,7 ; pp.5,8].

Conclusion

To wrap up, there are three points to recap. Firstly, it is about the idea of the glazing robot. We have saw the importance of treating the concrete in order to achieve better durability and minimize the wear range taking into consideration atmospheric and chemical factors. While the hydro-erosion offers good and cheap solution [pp.587, 1], laser glazing can be better alternative in terms of number of periodic preventive maintenance and technically in terms of improving the resistance of the concrete to detergents, minerals and acids causing multiple defects enumerated earlier. Secondly, in contradiction of the hydro-erosion technique, glazing does not depend on water availability and flow rate and pressure.

The second point is about the simulation of the glazing robot. As was discussed, the laser beam should reach the slab as well as walls. Hence lifting mechanism is supposed to orient the beams with reference to the vertical plan. We have selected the technical specifications of the cart and lifting mechanism in such way to be compared with the hydro-erosion robotic solution.

Later, the control task was formulated as two dimensional inverted pendulum problem. Assuming, that the cart is moving in a relatively smooth working site, the value of the friction coefficient between the wheels and the ground was chosen to be of minimal value. This coefficient plays important role in stabilizing the lifting mechanism as it can cause nonlinear curve form of the cart movement. Accordingly, the synchronization of the wheels rotation is an essential factor, which was not taken into consideration in our simulation [pp.14; 10]. In case all these factors needs to be considered, adaptive control system is recommended instead of the classic PID regulators offered in this paper.

We have also considered that the rotational movement of the lifting mechanism is achieved without friction around the pendulum centroid. The lifting arm is considered to be ideally rigid. As it can be seen, this is an idealized scenario, which cannot be considered in real practice when lifting the laser beams to six meters height.

Taking into consideration all the aforementioned constraints in the simulation phase, it is believed that the control task was resolved in terms of stabilizing the lifting mechanism while moving the carrying cart smoothly on working site.

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Critical Analysis of Factors Affecting the on-site Productivity in Indian Construction Industry

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Abstract

The growth in construction productivity is low and do not continue for a long span of time. The purpose of the present research paper is to identify the factors affecting the on-site construction productivity, from the literature review and through a focused interview with industry professionals. The most relevant 18 attributes have been finalized for the study, and a total of 154 complete data collection is targeted for the study form major contractors, developers and consultants throughout India. The convenient sampling technique is used to collect the data. The collected data has been analyzed using relative importance index (RII) to priorities the variable on the basis of their relative importance. The findings of the study conclude that the most significant 3 attributes affecting on-site construction productivity are planning and scheduling, availability of material, and storage area for a material having a relative value of 0.78, 0.76, and 0.75 respectively. SPSS 21 software tool has been used to check the reliability of the data and to perform factor analysis. The factors are site management, competency management, commitment and coordination management, resource management, and planning explains a variance of 15%, 11.5%, 10.3, 9.1, and 7.1% respectively. The research paper attempts to provide an insight and better understanding of the factors affecting on-site construction productivity in India and the ways and means to control and improve construction productivity of construction projects.

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Keywords: Construction Productivity; Construction Industry; On-site Productivity; Project Management; and Indian Construction Industry.

1. **Introduction**

Completion of a construction project on time and within budget is one of the main focus and key objective of a construction manager/project manager. It is however not that simple because a construction project is like a living entity and it requires interconnection and coordination of a number of stakeholders and many of them have their individual targets and goals, which sometimes create a conflict of interest between the teams and within the teams. The success of any project is repeatable and it is possible to find out a set of attributes for the success of a construction project and it requires a controlled discipline and hardworking. The productivity of construction projects is one of the measures for performance of the construction projects at the industry level based on its relationship with economic development. The most countries encounter the issue of low productivity as per the statistical data available in the public domain (OECD, report). The majority of the construction projects are suffering from two main issues those are delay in completion, and cost overrun. According to [1]–[5] poor productivity is one of the primary reasons for it. The productivity of a construction project is affected by a number of attributes either directly or indirectly. So the loss of revenues due to low on-site productivity of construction projects is one of the main areas of discussion for the researchers. And a number of researchers concluded that the productivity can be improved through a proper control mechanism of the attributes affecting productivity. The current research focuses on identification, analyses and grouping of the critical factors affecting on-site construction productivity in the Indian context.

The construction industry is having a significant role in the nation's development and it contributes about 8-10 % to the nations GDP on an average[6]. The construction industry in any economy is considered to be one of the major contributors to the gross domestic product (GDP) of that country. The majority of the population is connected directly or indirectly to the construction industry for basic living infrastructures like housing, transport, hospitals, and schools. Indian construction industry is the 2nd largest contributor to the employment pool, after agriculture sector. Thereafter as emphasized before, the industry lacks largely in the area of integration work, hindering its performance and appreciation. The industry has a bad reputation due to insufficient customer satisfaction, its inability to meet time and cost estimates, lack of predictability and poor quality. Hence focus in recent research has shifted to what causes this problem.

The Indian construction industry has contributed to 8 percent on an average in the last five years of the Indian GDP (as per planning commission of India 12thfive year plan, 2015). The construction industry has around 31,000 enterprises and provides job to around 41 million employees and the Indian construction industry is second largest job provider after the agriculture sector [1]. As per 2011 census, 68% of the residential buildings are in rural areas and 32 % in urban areas. The number of people employed by the construction industry in India was 14.1 million in 1951 which increased to 41 million people in 2011, a 300 percent growth in employment observed in the last 6 decades in the Indian construction industry. Out of which 31000, estimated enterprises 95% of the enterprise operates on a small scale. Construction productivity can be defined the ratio of total output obtained per unit of input or it can be defined as the rate with which the work is performed in the project. In the construction industry output needed for productivity are in terms of weight, length, volume and the inputs are generally calculated in terms of man-hours or cost of labour.

1.1 *Construction Industry*

The construction industry is one of the most important and significant sectors and supports the economic development of a country. It contributes to the economy, promotes growth, provides employment to the masses, and established a linkage between the economy and other industries ([2] [3] [4]. The construction sector is the engine of growth for a country and creates a flow of services and goods with other sectors [5]. Improving construction productivity enables to save the cost of per capita and also increase the revenue of the firms. Increase in the revenues from improved CP provides an additional flow to the economy and as construction industry provides a linkage to all other industries as a part of their business process. The measures to be adopted to improve the performance of construction projects has been identified critical and troublesome problems [6]. [7].The construction industry faced a number of issues including low rates of productivity growth and declining growth that have been entertained by a number of researchers for many years [8]. The firms are aware of that issue and investing to know the reasons for declining the productivity [9].

1.2 Construction productivity

"In general terms, construction productivity can be simply illustrated by an association between an output and an input i.e. Productivity= Output/Input". Productivity is commonly defined as a ratio of a volume measure of output to a volume measure of input use (OECD Manual) [10]. The productivity could be measured at various levels, but there are three main measures of productivity are metronomic, case, and pricing studies [11]. The financial wealth of nations is determined by their productivity growths (Smith, 1776). The nations experienced higher productivity growth translated into increases in the average wages of the workers, which contributes to the profits and tax revenue collection of the countries [11]. Researcher's tried to understand the relationship between skill development and productivity in the construction industry. The trend is not consistent over time due to a number of reasons such as unplanned training sessions, consistency of skill development courses and the decrease in the number of participants [12][13]. Construction productivity has been the area of interest for the research since last 4-5 decades. A number of studies have been conducted in the field which includes: analysis of productivity, measurement techniques, and causes of low productivity, factors affecting construction productivity, simulations models, a framework for improving CP and other studies

2. **Literature review**

Productivity has been one of the most researched topics in the Indian construction industry in the last few decades. Factors affecting productivity may have a short-term or long-term effect on the project, some affect the productivity for a short duration but have a ripple effect on it. Productivity consists of various attributes like labour, finance, infrastructure, plant & machinery, facilities etc. Various studies in different countries have been carried out to identify the factor affecting labour productivity. Various methodologies and approaches have been adopted by researchers who have come with different schemes in the categorization of factors affecting productivity [10]11]. [12]Classified factors affecting productivity into internal and external factors. Internal factors were termed for those factors which are beyond the control of management and External factors for those factors which arise or originate in and around the workplace. [7] Introduces a regression model that established a linking between worksite productivity to process improvement initiatives (PII). This model provides insight and helps the industry to predict the expected value of productivity at the beginning of the project on the basis of certain inputs such as design competition, project manager's dedication, project vision and others. The model was created specifically from temporary worker particular data and subjected to thorough factual investigation. The model gives project supervisors as front-line industry workers to ponder and reasonable way to deal with project management and productivity improvement. [8] Has studied the impact of poor productivity of construction workers on the cost and delay of the projects. And the findings suggest that cost and timely completion of any Project is significantly dependent on the workforce productivity. Analytical hierarchy process used to prioritise the factors affecting workforce construction productivity and the finding suggests that major significant factors are planning and schedule related. A number of researcher's identified and analyzed the factors affecting CP in different scenario's and ranked them on the basis of their severity of impact and relative importance index values derived using different approaches such as: reliability importance index, some statistical tools, analytical hierarchal analysis, principal component analysis or factor analysis, SOM-based models, system dynamics based approaches, and other tools and techniques[9] [10] [11] [12] [13] [14] [15] [16] [17] and [18].

Table 1 attributes affecting on-site construction productivity

Attributes/variables	*References*
Increases in land-use regulation	[19]
Equipment, drawing, tools, availability of material, weather condition	[20], [14],[21], [22]
Labour management, rework, material, confined working space, tools	[23], [24]
Delays in inspection, decision taking, material, rework, tools and equipment	[24]–[26]
Absenteeism, Rework and lack of material	[9][27], [12] [28] [11][29] [15] [9][30]
Shop drawings, equipment's, motivation and support, scheduling, material	[31] [8], [23], [32], [33][34]
Revision in drawings, delays in inspection, competency of supervisor, martial availability	[24] [27], [29]-[15], [35][36][6]
Project management, planning and scheduling, top management support, rework	[7], [37],[38]
Coordination among all team members, leadership, top management support, the flow of funds, budget update, coordination and communication, timely feedback, and owner's competence and favourable climatic condition.	[39][40], [41]
Rework, Poor supervisor competency and Incomplete drawings	[24], [42], [43] [23], [35], [37] [44]
Decision making, planning & logistics, supply chain management, labour availability, budget & cash flow management, improper construction method, frequent changes in design, supervision delay, the sequence of activities, overcrowding a job location and scope of activities.	[40], [13][32] [45][41]
Availability of material, the experience of labour, skill set and training, communication, the financial position of the client	[33][32], [14]

Table 2 findings of previous studies (attributes affecting construction productivity)

References	*Findings (ranking of the attributes)*

[9] and [10]	Availability of material	Drawing management	Coordination	Construction equipment	Tools and consumables
[11]	rework	truck availability	Materials	equipment	Tools
[12] and [13]	Management	technology	labour availability	climate	education and experience
[14]					
[15]	Labour skills	coordination	supervision errors	drawings	delay in response to information
[46]	Temperature	height			
[16]	The findings of the study suggest that craft labour productivity shall be improved using material tracking technologies.				
[18]	The authors proposed and validate a SOM-based model to analyse the relationship between crew productivity and various factors.				
[17]	The authors identify and measure a four-component decomposition of the temporal changes in construction labour productivity, including technology, technology-utilization efficiency, the capital-labour ratio and production capacity.				
[47]	The findings of the study suggest a consistent decline in the productivity of output /labour/hour				
[40]	The findings of the study suggest that high sustainable productivity shall be achieved under good management practices				

3. **Data collection**

To achieve the desired objective the data for the study were collected through a structured questionnaire survey of 112 construction professionals and academicians from all over India. The questionnaire consists of 21 questions attempting to cover the major factors affecting on-site productivity. The factors have been identified with the help of various studies on construction labour productivity. People with required qualification and experience answered the questionnaire, so it can safely be assumed that the data obtained has credibility and can be used for the study as the respondents are conversant with the problems related to labour productivity and factors affecting the construction productivity.

3.1 Relative importance index

The received responses by the respondents were summarized in an Excel data sheet and the data analysed using SPSS software. Relative importance indices (RII) is performed to determine the priority of the significant factors and then followed by Reliability analysis performed to check the consistency of the data received.

$$\text{Rii} = \frac{\sum_{r=1}^{5} r * n_r}{5N} \quad (1)$$

'r' is the rating on a Likert scale (1-5) as for the impact on construction efficiency for a specific element influencing construction profitability, 'n' is the number of respondents providing a specific Likert scale rating r, 'N' is the aggregate number of respondents to a specific question [6].The respondents were asked to rate the questions using a five-point scale '5' being the very high, '4' high, '3' moderate, '2' low, '1' very low impact on on-site productivity.

3.2 Reliability Cronbach's alpha value

Dependability analysis is required to check the consistency of the data, and Cronbach's alpha test was the best way to check the reliability of the data collected through questionnaire [29]. The value of Cronbach's alpha for this study is 0.715 which is considered to be good (table 3) [29].

Table 3reliability/Cronbach's alpha for the attributes

Description	Cronbach's alpha
All attributes selected for the study	0.715

4. **Result and findings**

4.1 Most significant factors

The most significant factors affecting the on-site productivity in Indian construction projects are planning and scheduling, availability of material, and storage area for material [48] having a relative importance index of 0.78, 0.76, and 0.75 respectively (table 2).

4.2 Significant factors

The significant factors affecting the on-site productivity in Indian construction projects are frequent changes in drawings, periodic meetings among management and contractor 's, and change in scope [49][50] having a relative importance index of 0.74, 0.73, and 0.70 respectively(table 2).

Table 4 ranking of attributes on the basis of relative importance index

Rank	*Total Responses*	*Total Score*	*RII*	*Attributes affecting the on-site productivity of construction projects*
1	112	435	0.78	Planning and scheduling
2	112	428	0.76	Availability of material
3	112	421	0.75	Storage areas for materials
4	112	415	0.74	Frequent change in drawings
5	112	408	0.73	Periodic meetings with management, Site personnel and contractors
6	112	393	0.70	Change in scope
7	112	389	0.69	Job Security/appreciation
8	112	386	0.69	Pep talk
9	112	383	0.68	Working Condition/Confined space
10	112	372	0.66	Type of Construction Methodology
11	112	371	0.66	Absenteeism
12	112	369	0.66	Adequate Crew and composition
13	112	368	0.66	Proper timely inspection by engineer
14	112	367	0.65	Rework
15	112	364	0.65	Proper training provided prior to execution of work
16	112	362	0.65	Poor construction method
17	112	357	0.64	Direction and coordination/communication
18	112	356	0.63	Experience of Management

Table 5 factors analysis

Attribute/Factor	*Factor loading*	*%age of variance explained*
Site management		*15%*
Training	0.53	
Availability of material	0.84	
Working condition	0.57	
Working hours	0.65	
Competency management		*11.5%*
Rework	0.46	
Poor construction method	0.55	
Job security	0.59	
Commitment and coordination		*10.30%*
Response to change order	0.55	

Revision in drawings	0.79	
Pep talk	0.61	
Periodic meetings with management and site personals	0.55	
Resource management		*9.1%*
Storage area for material	0.49	
Adequate crew and composition	0.63	
Planning		*7.1%*
Change in scope	0.49	
Project management	0.63	
Total variance explained		*53.3%*

4.1 Factor analysis

Factor analysis enables us to reduce the number of dimensions of the data and to draw a table on the basis of variance explained by the constructs/factors, and factor loading of the different attributes in factors. For the current study, the attributes having a factor loading of equal and more than of 0.4 has been considered[8]. The factor analysis reduced 18 attributes into 5 factors explain a cumulative variance of 53.3%.

4.1.1 Site management

Pre-construction management explains the maximum variance of 15% for the attributes affecting on-site CP. The attributes having the factor loading more than 0.4 are training, availability of material, working condition, and working hours having a factor loading of 0.63, 0.84, 0.57, and 0.65 respectively.

4.1.2 Competency management

Decision management explains a variance of 11.5% for the attributes affecting on-site CP. The attributes having the factor loading more than 0.4 are rework, poor construction method, and job security having a factor loading of 0.46, 0.55, and 0.59 respectively.

4.1.3 Commitment and coordination

Stakeholder's management explains a variance of 10.3% for the attributes affecting on-site CP. The attributes having the factor loading more than 0.4 are a response to change order, revision in drawings, pep talk, and periodic meetings with management and site personals having a factor loading of 0.55, 0.79, 0.61, and 0.55 respectively.

4.1.4 Resource management

Coordination and communication explain a variance of 9.1% for the attributes affecting on-site CP. The attributes having the factor loading more than 0.4 are a storage area for material, and adequate crew and composition having a factor loading of 0.49, and 0.63 respectively.

4.1.5 Planning

Resource management explains a variance of 7.1% for the attribute affecting on-site CP. The attributes having the factor loading more than 0.4 change in scope, and project management having a factor loading of -0.61, and 0.4 respectively.

CONCLUSION

The study aims to identify and analyze the factors affecting the on-site productivity in construction project through an empirical study. The study reveals that the average value of reliability analysis for all the attributes is above 0.63 i.e. all the attributes selected for the study having a significant impact on on-site productivity. The most significant attributes impacting on-site productivity are planning and scheduling availability of material, and storage area for materials. The maximum variance is explained by site management, and the least variance explained by planning is 15%, and 7.1% respectively. This study reveals the main factors affecting on-site productivity in India through a structured questionnaire survey. The results of the study shall benefit the industry to improve their productivity.

Limitations

The study is conducted using structured questionnaire survey and collection of primary data. The received responses are 112 considered for this study is comparatively small to generalize the findings to the larger scale. It is recommended to conduct a similar kind of study in different regions of the country to have a better understanding of the factors affecting on-site productivity in construction projects.

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Evaluation of the construction project success with use of neural networks

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Abstract

Construction project success is determined in terms of cost, schedule, performance and safety through many events and resultant interactions, plans, facilities and changes in participants and the environment. In the construction industry there are myriad uncertainties that make management exceedingly complex. Factors for success vary from project to project. Human experts can often achieve a satisfactory project outcome, however, shortfalls nearly always occur due to managers failing to take all relevant factors into consideration, in addition to lacking access to all relevant information. Statistical methods represent a basic approach to identifying significant factors from historical data or questionnaire results. However, the dynamic nature of critical factors means that changes in project conditions must be monitored continuously. Artificial intelligence techniques have a wide range of applications, including monitoring and forecasting of long-term projects; their main advantage is the ability to track and predict trends in changing project implementation factors. In this article, the authors describe the structure and algorithm of the neural network for assessing the success of construction projects, taking into account the individual influence of the initial conditions as well as their combined impact.

Keywords: Construction project success, neural network, artificial intelligence techniques ;

1. Introduction

Once a construction project has been proposed, the primary contract is typically subdivided into multiple subcontracts. Large numbers of participants are, therefore, involved in project planning and implementation phases (see Fig. 1.). Expectations can only be met by conducting a comprehensive analysis of participants [1-4]. Project

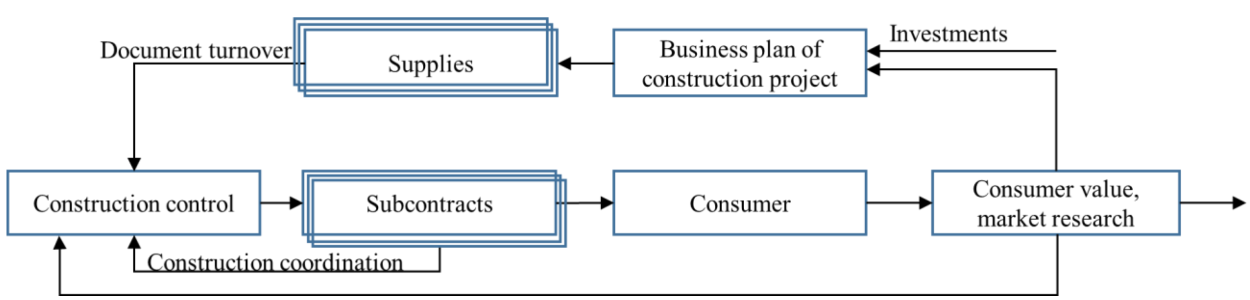

Fig. 1. Basic information and resource flows of construction production

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success is determined in terms of cost, schedule, performance and safety through many events and resultant interactions, plans, facilities and changes in participants and the environment. Project managers able to identify key determinants to project success can monitor project performance continuously and make proper decisions based on objective performance predictions related to project success targets.

Artificial intelligence, a novel technology for extracting knowledge, is already widely applied to various civil engineering problems, including project management. To predict project performance, an appreciation of critical factors are crucial to achieve of the project objectives successfully. Statistical methods represent a basic approach to identifying significant factors from historical data or questionnaire results. However, the dynamic nature of critical factors means that changes in project conditions must be continuously monitored.

In the construction industry, neuro fuzzy intelligent systems are used not only to predict the technical performance of the construction project, but also to compare them with the results of statistical methods of reducing variables [5,6].

2. Success in construction industry

The final objective of construction management is to accomplish construction projects 'successfully'. From an owner's perspective, the definition of a successful project is one that meets or surpasses budget and schedule expectations. Consequently, a less-than-successful project fails to achieve budgetary and/or schedule expectations [7]. Project managers are responsible for project success, and must monitor project performance continuously in order to take proper corrective actions essential to controlling project progress.

Project outcomes are affected by different factors at various points in time. During the course of a project, predicting project outcomes at different stages requires an ability to analyze dissimilar factors [8]. A dynamic prediction methodology is thus required for project managers to monitor project performance on a continuous basis. However, each time, numerous time-dependent variables can affect project outcome. In addition, due to the nature of the construction industry, such variables remain uncertain [9]. While human experts can predict project outcomes based on their personally accumulated experience and knowledge, the significance of such judgments is restricted by their subjective cognitions and/or knowledge limitations.

3. Neural network for evaluation of the construction project success

For the proposed neural network, "hybrid" refers to the combination of traditional neural and high order neural networks. The high order neural network is constructed of three layers with a high order connection and a linear connection between the 1st and 2nd layers and 2nd and 3rd layers, respectively. This study extends the use of high order connections for all connection alternatives, i.e., all layer connections can switch between linear and high order formats (see Fig. 2). An HNN neuron is dominated by an alternative of the following equation:

Linear connection: $y_i = f(\sum w_{ji} x_i + b_{j0})$; (1)

High order connection: $y_i = f(\prod x_i^{p_{ji}} * 1^{b_{j0}})$; (2)

Activation function: $f(x) = \frac{1}{1+e^{-ax}}$; (3)

where w_{ij} – coupling weight coefficients; y_i – output neuron signal; x_i – input neuron signal.

An activation function f uses a sigmoid function with a slope coefficient of a. Therefore, each layer connection features an attached connection type that represents the corresponding operation selection (see Fig. 2).

This implies that each layer depending on the operating mode may change the type of connection between neurons. For example, for a neural network consisting of 3 layers, the following options are possible (linear - L, higher order - HO): L-L; L-HO; HO-L and HO-HO.

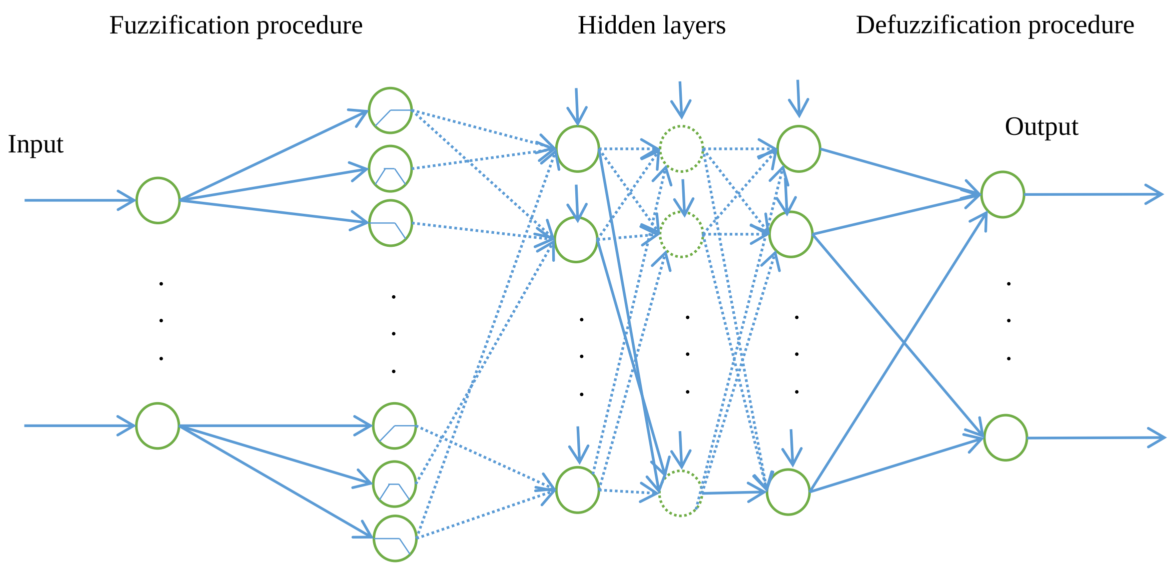

Fig. 2. Hybrid Neural Network Structure

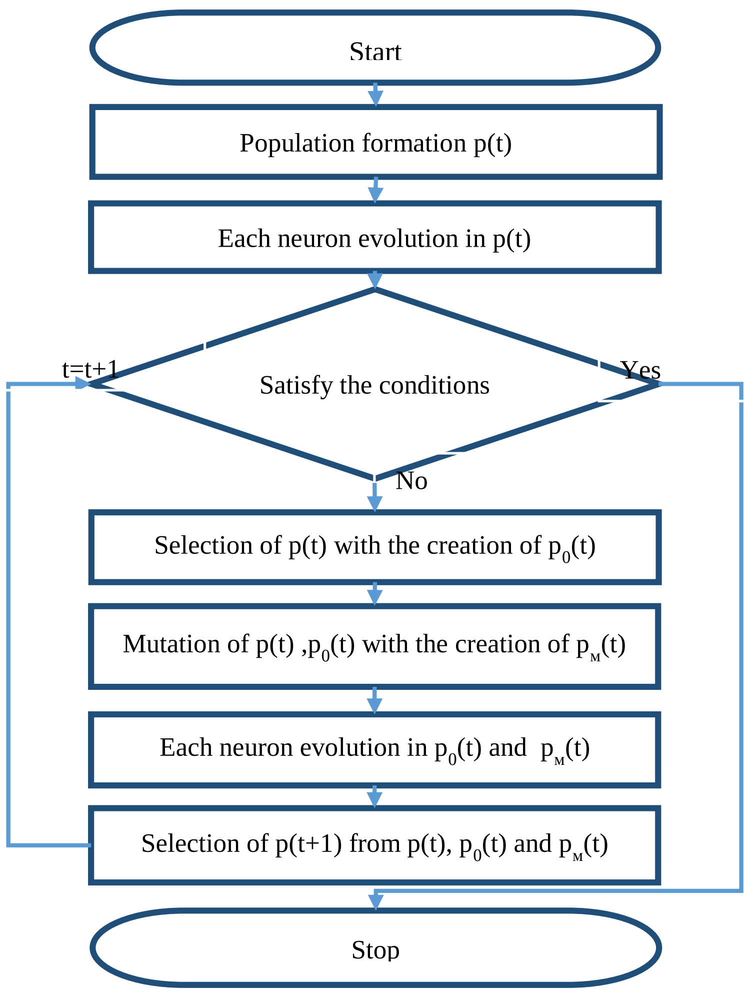

Fig. 3. Optimization genetic algorithm

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4. Optimization genetic algorithm

Optimization of the created neural network is possible with the help of the genetic algorithm adaptation [10, 11] (see Fig. 3). Genetic algorithm, which imitates elements of the natural evolution process, were first proposed in Holland [12]. To apply the genetic algorithm to problem optimization, one must identify all essential parameters to determine chromosome length. The chromosome (i.e., one individual) in this study represents neural network parameters: interconnection coefficients, connection types, a slope coefficient of activation function, and network topology (total layers and layer neurons). Fuzzy logic parameters include membership function summit points, membership function widths and defuzzification weights.

Genetic algorithm is a method of random search with elements of adaptation, which is based on principles similar to the Darwin's evolution process of biological organisms. In this case, three types of operations are performed: crossing, mutation, selection. The fitness degree (how the population corresponds to the given task) is defined through the fitness function that can also include penalty functions for violation of additional restrictions on variables. There are various forms of crossing [13]. They make a selection of the fittest specimen, which constitute a parental pair and the crisscrossing of the chromosomal chains takes place, i.e. the descendant line code inherits fragments of codes of parental chromosomes. The selection operator allows the creation of a new population from a set of specimen, which are generated and modified descendants of specimen after mutation. The genetic algorithm is used to adjust the membership functions that are defined within the accuracy of a few changeable parameters, such as triangular, trapezoidal, and radial functions. When simultaneously configuring several membership functions, the parameters of each are coded by their own segment of the chromosome, so that during the process of crossing the code, sharing occurs only between chromosome segments of the same type. For configure the rule base, to each element of the chromosome is assigned an element of this rule base and based on the received encoding is selected a type of genetic operator. Thus, the architecture of the systems for evaluation of the construction project success can be represented as follows (see Fig. 4).

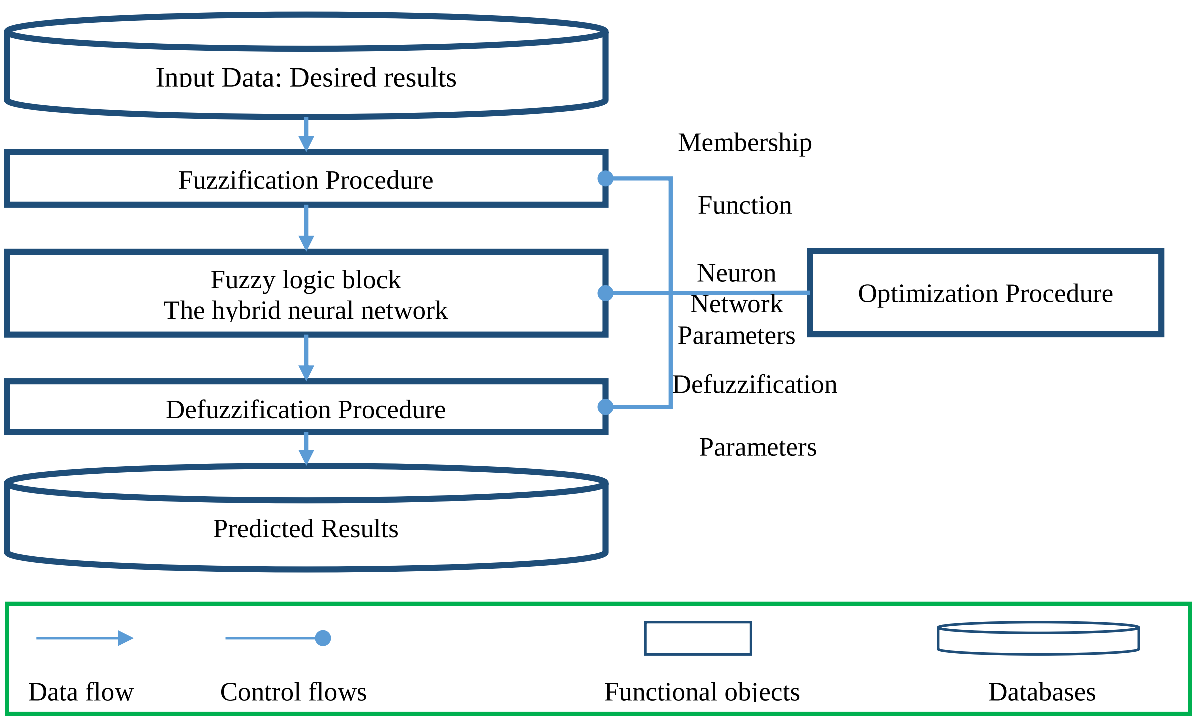

Fig. 4. Architecture of the systems for evaluation of the construction project success

Conclusions

This paper described an evolutionary fuzzy hybrid neural network to enhance project cash flow management. Neural networks and high order neural networks are combined in the developed evolutionary fuzzy hybrid neural network to form a hybrid neural network, which acts as the major inference engine and operates with alternating linear and non-linear neural networks layer connections. Fuzzy logic is employed to sandwich the hybrid neural network between a fuzzification and defuzzification layer. The authors developed this evolutionary fuzzy hybrid neural network to assess construction industry project success by fusing hybrid neural network, fuzzy logic and genetic algorithm.

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INTEGRATING SOFTWARE AND HARDWARE TO ENHANCE CLASSROOM BIM INSTRUCTION

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Abstract

University based construction management programs typically instruct students in the use of Building Information Modeling "BIM." The students' interactions with BIM require them to perform exercises using computer software related to modeling, estimating and scheduling. Most of the students' BIM interactions are confined to software environments and do not make connection with the construction environment. Some students may be more focused on the built environment and may be less comfortable behind the computer. They may not as eagerly adopt BIM or see the benefits of using this tool in the field. To bridge this gap, a program has been developed that combines BIM modeling with advanced robotic surveying equipment and unmanned aerial systems (drones).

Auburn University Building Science students complete a project prior to graduation which combines all skills learned throughout the curriculum. Students select different buildings for their project and one requirement is to model the foundation and superstructure of the building from 2d construction drawings. With the 3d model complete, the students learn how to export the necessary data and utilize robotic surveying equipment to outline their foundation in an outdoor grassy area. Photographic data is obtained using a drone, processed, and is then brought back into the BIM model to verify the accuracy of the physical layout. This paper details this program and looks at the software, equipment and techniques used to demonstrate the value of integrating BIM with work performed in the field.

Keywords: BIM, Drones, Surveying, Robotic Total Station

1. Introduction

Teaching in project management and technology courses over the years, it has been observed that a certain demographic of construction management students do not engage in BIM exercises and BIM centered classroom discussions. That type of student is typically more focused on the field supervision/tactile side of construction management rather than project management. In an effort to persuade that type of student of the advantages and possibilities of BIM and other advanced technologies, an attempt is being made to connect the software with hands-on construction related tasks. It is believed that seeing the usefulness of BIM for practical tactile tasks will inspire students to engage more fully in BIM. BIM software has a steep learning curve and can be discouraging for students who have just begun to use the tools. [1] In addition to the requisite computer skills, one of the challenges with BIM software is that it is akin to virtual building, therefore to be proficient in BIM the user needs to have a lot of technical knowledge and experience. The same type of technical knowledge and experience that is desired by those inclined to engage in field supervision is extremely useful for BIM user proficiency. [1] Therefore, engaging this demographic with BIM is a more natural marriage then it may seem at first.

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In addition to the increased use of BIM in the construction industry, it is important for construction related programs to prepare their students with BIM-related skills and knowledge that they will be expected to possess once they enter the workforce. [2] Adequate BIM knowledge, skills and abilities is essential to advancing the construction industry into the BIM age. In parallel with industry, construction management programs need to integrate BIM within their curricula ensuring that students enter the workforce with the requisite BIM knowledge and skills they will need in their future careers. Therefore, both industry and academia need to focus on BIM training and education to maximize the values and benefits from the use of BIM. [2] Construction Management programs can play a vital role in BIM education and training thereby lowering the internal training burden of construction companies. Without a doubt, the demand for more individuals with experience and knowledge of BIM technology and VDC practices exists. [2] BIM use has grown from a design tool into a near necessity for delivering major construction projects. [3] It is no longer a viable excuse for a student to claim that they desire to become a field supervisor therefore it is not necessary that they develop BIM skills. BIM skills will be required and utilized by all the onsite management staff at a construction site. It is therefore critically important that we as educators use extra efforts to reach out to those students who remain comfortable being unengaged with BIM.

1.1 BIM Layout

Seniors in Auburn University's Building Science program have to pass a course titled "Senior Thesis." This course tends to be very rigorous and requires a tremendous amount of effort from the students. It is a whole project simulation requiring students to submit a number of deliverables including; a BIM model of the structure, estimate, schedule, pay applications, and many other project documents. This is an intensive process for students and requires them to display a wide range of knowledge skills and abilities. Students are also required to produce some work which is of their own choosing. This section of their thesis is referred to as "student selected" work and is required to involve approximately 40 hours of work with a direct relation to their project. Other than that, students have flexibility in what they choose to do and is an opportunity for the students to pursue their own interests and passions. To help students fulfill this requirement various suggestions are provided, along with various previously approved deliverables from which they can choose. If none of these options interest the students, they are allowed to develop ideas of their own.

One of those a la carte electives for student selected work has been a layout exercise where the students take their structural model and physically lay out the foundations. By design, this exercise is intended to reach those students who are not engaged in BIM by connecting a hands-on practical construction activity with BIM software. In order to complete this exercise, students must model the foundations of their building and attach points to those modeled elements to allow them to complete the layout. These points correlate with an X, Y, Z coordinate system which is recognized by the surveying equipment.

All students use Autodesk Revit to create their structural model. After creating their structural model in Revit students utilize Autodesk Point Layout (Revit Plugin) to generate a list of points to be loaded into the total station. In addition to Autodesk Point Layout, points can be generated natively inside Revit. When using this advanced type of surveying equipment, the students simply export a .dwg file and import that into the surveying tablet where the points are easily generated. All the methods described above can be used to arrive at the same place which is to have points generated from your BIM model loaded into your total station ready for physical layout.

At Auburn, with a limitation on the number of hardware devices and space to complete the layout exercise, typically only one group can be accommodated at a time. To complete the layout exercise, students use the following two pieces of surveying equipment which have different capabilities. When the program was started, students used a traditional two-person total station, the Leica model TS06. As the program grew in popularity, an advanced robotic total station was purchased allowing students to complete the exercise on their own.

It appeared that the student's interest in the exercise grew once the robotic total station was acquired. The two types of total stations are shown below in figure 1.

Figure 1: (a) Two-man Total Station (b) Robotic Total Station

Total stations are inherently complex and faculty members can spend an inordinate amount of time instructing students on how to efficiently use the hardware. The robotic total station it a little more user friendly but still requires a significant amount of one on one time with the students to show them how to complete the exercise. To correct this problem, a series of short instructional videos were produced on how to operate the hardware and software. The videos can be found via the attached link.

https://www.youtube.com/channel/UCGEExyLdGoDSbqWjxfuCNWw?view_as=subscriber

In addition to the surveying hardware that the students use to mark out their layout in the field, an unmanned aerial vehicle (UAV), or drone is used to photograph the layout from above. The photographs are currently being acquired using DJI's Inspire 1 Pro with the Zenmuse X5 camera equipped with a 15mm lens. These aerial photos allow students to get a bird's eye view of their layout work and really get an appreciation for precision achieved by the surveying equipment. This UAV technology is another type of technology that is well suited to the field and those individuals inclined toward field operations. See a picture of the UAV utilized in figure 2 below.

Figure 2

2. Methodology

This a la carte exercise has been offered to senior thesis students over the past three years. In that time period there have been over nine sections of the thesis class averaging between 30-45 students per semester. Each semester in which the exercise has been offered as a student selected work activity, more than half of the students in the thesis class have elected to participate in it. A conservative estimate of approximately 150 students have elected to perform the exercise over the past three years and it has been consistently well received.

Students have been required to complete this exercise in groups no larger than three. Student groups collaborate on one of the group member's models and utilize it for field layout. The software integration between Revit and the survey instrument typically takes about an hour. Depending on the number of points to layout, the field work can take the student groups between 4-8 hours. After the points are identified students use flower to mark the dig lines for their footings. After all this is complete the students are required to write up a single page reflective piece about the exercise that becomes part of their deliverable for thesis. The images included below in figure 3 show the Revit model used to establish the points and on the left side and aerial photographs of the completed field layout on the right.

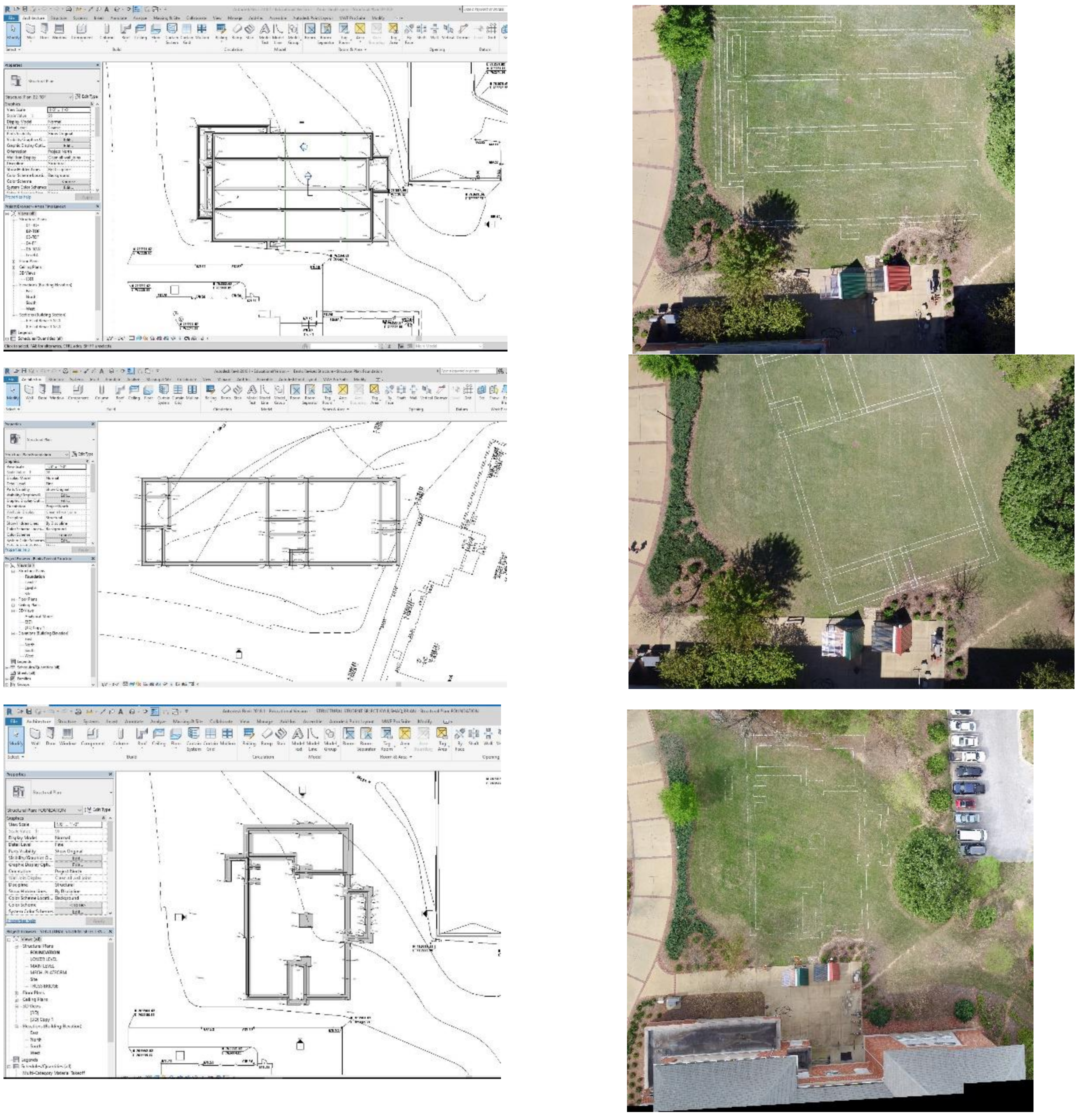

Figure 3

Of the multiple students who have completed the exercise, seven have been interviewed concerning their perception of this exercises' utility as a teaching tool and bridge to engage non-technical students. The interview questions were structured to discovered whether or not an exercise of this type could inspire tactile personality types to engage with BIM and other advanced technologies such as UAVs.

The first question was a demographic question about the participants. The first questions asked the students, "Do you consider yourself a "BIM Person", (i.e. do you feel that this is a primary part of your expertise and/or skillset?)" Figure 4 summarizes these results.

-Not really but I do appreciate it and see the value of it.

-Yes

-No I do not consider myself a "BIM Person", but I do fell proficient w/ the program.

-I believe I am competent, but not highly skilled at it.

-Yes, I do consider myself a BIM Person.

-I would not consider myself as proficient as some w/BIM but I am very capable of using it. I do value it and see how it can make some activities run more efficiently.

-No, I see the value in BIM but it is not something I would consider as a primary part of my expertise

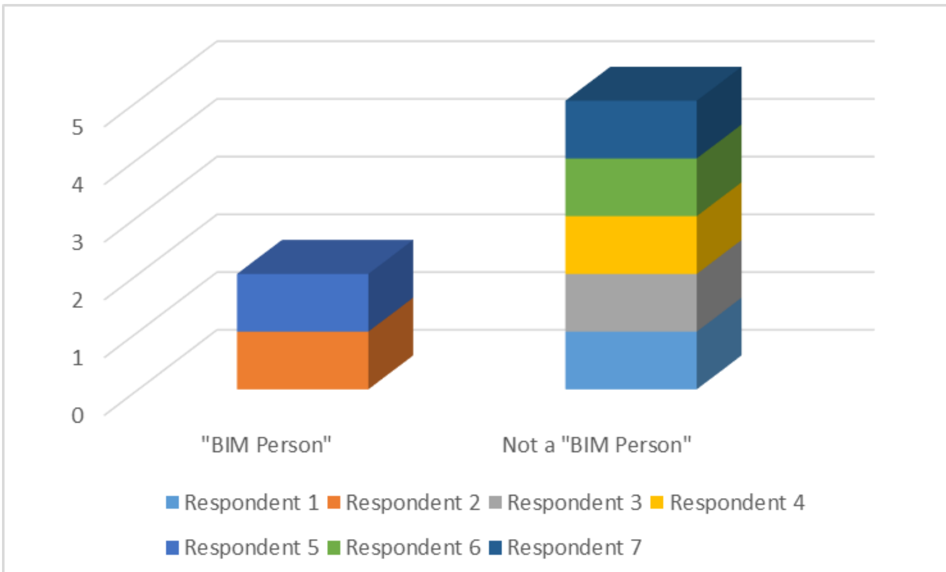

Figure 4

The second question was also a demographic type question "Do you consider yourself a "Superintendent Type" employee, (i.e. do you feel that this is a primary part of your expertise and/or skillset?)" Figure 5 summarizes the responses below.

-I consider myself more of a pm guy.

-I enjoy being onsite but don't envision being a superintendent

-Yes, I am going into the field side post college

-No. I consider myself more skilled for the management side of construction.

-I am a superintendent type employee

-Yes, I do consider myself a "superintendent type" person. I like getting my hands dirty, being onsite & solving problems as well as interacting w/workers. I am a lot better at hands on than using software or doing "PM" work.

-Yes, I enjoy being out on the site interacting with the trades.

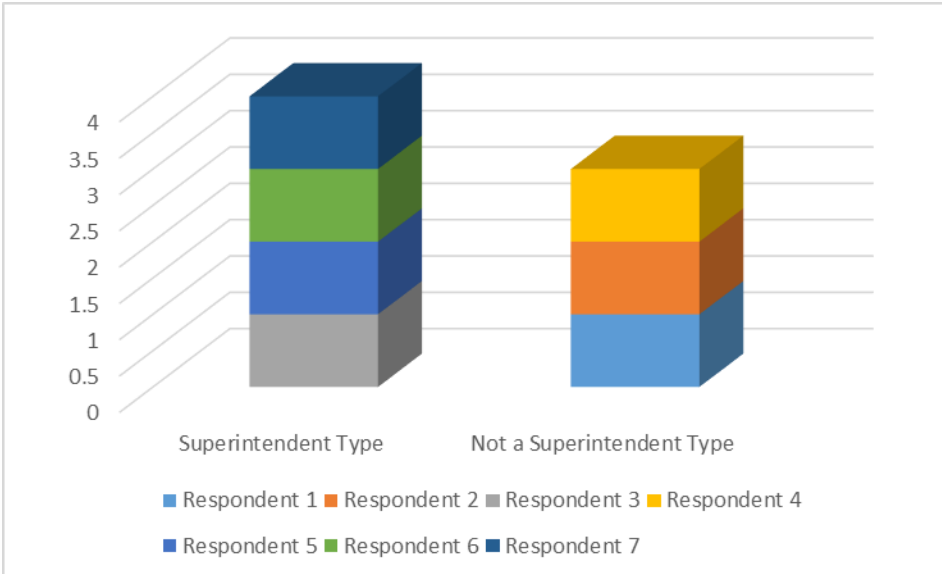

Figure 5

The third question asked about their perception of field type personalities "Is it your opinion that "Superintendent Type" personalities don't value BIM, and in general are less likely to use it as a tool to improve the efficiency of their everyday workflows?" Figure 6 summarizes the responses below.

-Yes, I agree with this.

-Yes

-Yes old school superintendents are hesitant w/ using new tools.

-I believe that the younger ones have come to appreciate it more, but the older superintendents enjoy doing things the old fashioned way.

-The past tells us that Superintendent type personalities do not value BIM or any tool that makes things easier and more efficient for that matter. However, I feel that younger employees are helping change that.

-Yes, typically "Superintendent Type" people do not value BIM. "Superintendent Types" tend to be more technologically inept so it is not common or practical for them to use it to improve efficiency.

-Depending on the size company, larger companies have the resources to train superintendents on new BIM technology. Smaller companies don't value BIM in the same way because of cost.

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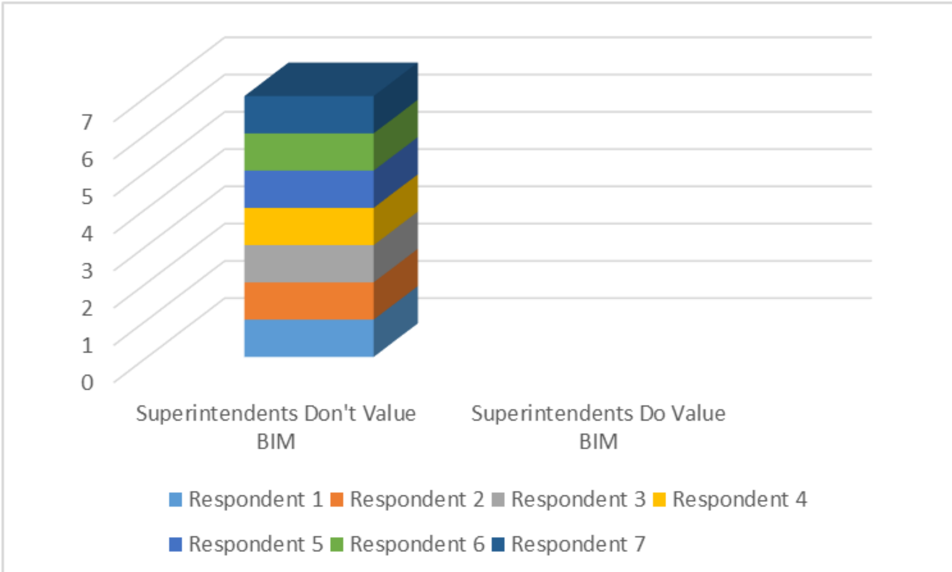

Figure 6

The last question I asked had to do with whether or not the respondents felt that a hands-on activity like using the model for foundation layout could potentially inspire “Superintendent Type” personalities to engage with BIM software more readily. Figure 7 summarizes the responses below.

-Yes, I do believe that it would, even knowing and being familiar with my BIM foundation model made it easy to layout the foundations.

-I think it will be tough to move from the old way of layout due to difficulty with the technology

-Yes, new people, like myself, will be willing to use the new technology

-Yes.

-Yes, I believe it would inspire. After doing that exercise, people would be crazy not to be a fan of BIM.

-Yes. I will say that it has already made me more interested in BIM. Definitely after seeing its efficiency on interior slab layout.

-Yes, assuming they get the proper training I believe that the “Superintendent Type” personalities would engage more with BIM.

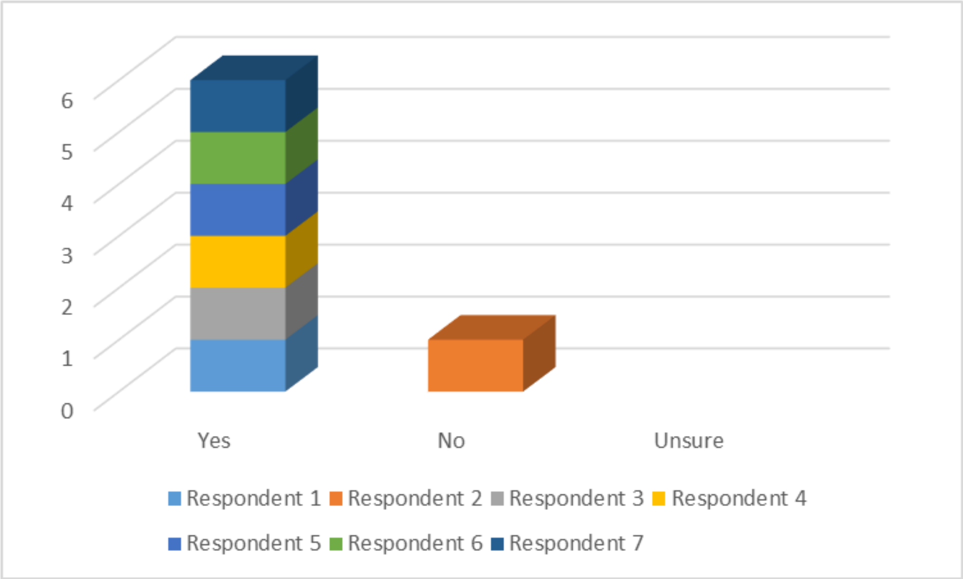

Figure 7

3. Conclusions

Prior to conducting the formal interviews cited in this research, informal feedback was received from all the students participating in the program. From this feedback the program is believed to be successful in engaging and drawing tactile non-technical students toward BIM and other advanced technologies. After seeing the results of these interviews this ad hoc opinion was confirmed and the exercise appears to accomplish its intended purpose. The research certainly is preliminary in its results and invites additional work and follow-up research. As was stated in the introduction advanced technologies such as BIM and UAVs will continue to grow in importance in the construction industry and it is imperative that our graduates are skilled in how to efficiently utilize these tools on their construction projects. Specifically, we as a faculty have a particular concern about engaging the type of student that considers themselves to be in the superintendent mold to both utilize and implement these advanced technologies.

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Blockchain in the built environment: analysing current applications and developing an emergent framework

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Abstract

Distributed ledger technology (DLT), commonly referred to as 'blockchain' and originally invented to create a peer-to-peer digital currency, is rapidly attracting interest in other sectors. The aim in this paper is (1) to investigate the applications of DLT within the built environment, and the challenges and opportunities facing its adoption; and (2) develop a multi-dimensional emergent framework for DLT adoption within the construction sector.

Key areas of DLT applications were found in: smart energy; smart cities and the sharing economy; smart government; smart homes; intelligent transport; Building Information Modelling (BIM) and construction management; and business models and organisational structures. The results showed a significant concentration of DLT research on the operation phase of assets. This is expected given the significant resources and lifespan associated with the operation phase of assets and their social, environmental and economic impact. However, more attention is required to address the current gap at the design and construction phases to ensure that these phases are not treated in isolation from the operational phase.

An emergent framework combining the political, social and technical dimensions was developed. The framework was overlaid with an extensive set of challenges and opportunities. The structured and inter-connected dimensions provided by the framework can be used by field researchers as a point of departure to investigate a range of research questions from political, social or technical perspectives.

Keywords: blockchain; distributed ledger technology, construction industry; built environment; smart contracts.

1. Introduction

Technological advancements and their adoption in the construction industry have been less effective to date than in other industries such as automotive, manufacturing and logistics [1]–[5]. £600bn will be spent on construction in the UK over the next 10 years to improve infrastructure; the efficiency and productivity of the sector are now strategic priorities of the UK Government's construction and innovation policies [6]. Building Information Modelling (BIM) is currently the expression of digital innovation within the construction sector [7]–[9]. If BIM is the main enabler for promoting collaboration, information sharing and data management, Blockchain is a possible solution to eliminating the trust element that often hinders these practices [8]. Blockchain is "*an emerging technology that enables new forms of distributed software architectures, where components can find agreements on their shared states for decentralized and transactional data sharing across a large network of untrusted participants without relying on a central integration point that should be trusted by every component within the system*" [10, p. 182].

The Blockchain, the first DLT, was introduced in 2008 with Satoshi Nakamoto's white paper on Bitcoin (the world's first cryptocurrency) [11] which was released in 2009 as a verification tool for cryptocurrencies but that also has the

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power to be applied to other applications [12]. blockchain has the potential to benefit the economic, political, humanitarian, and legal sectors by reconfiguring the workings of society and operations [13].

Blockchain is being explored for a number of different industries including, but not limited to health care [13], information sharing [14], information management, insurance, automated dispute resolution, real estate, [15], crowdfunding [16], big data analytics [17], and education [18].

The aims of this paper are to explore the current level of research on blockchain applications in the built environment and to develop a framework for its implementation within the construction sector. First, the paper explains the key concepts underpinning DLT and smart contracts. Second, it briefly explains the adopted systematic literature review approach and summarises the findings. Third, the paper discusses the challenges and opportunities facing the application of DLT within the built environment. Fourth, the paper presents an emergent multi-dimensional framework for DLT implementation in construction that considers the political, social and technical aspects.

2. Background

2.1 Distributed Ledger Technology

A distributed ledger is a simple database of transactions. Unlike a bank, where all transactions are processed and stored by one organisation (i.e. centralised), transactions on DLT are processed and stored across many different computers, known as nodes (i.e. decentralised) replacing trust with proof [19]. Trust is built into the technology through its decentralised nature and basis of consensus representing a paradigm shift from trust to a "trustless" society in which third parties become redundant [20]. Decentralisation, or decentralised trust, is a key feature of public DLTs transferring trust from people or intermediaries to computational code [21]. Centralised trust is the 'as is' situation where trust is put in one person, organisation or authority based on their knowledge, expertise or power in a certain subject area. Werbach suggests trust in centralised systems is waning with DLTs offering "a compelling alternative" [22, p. 58]. While it is not yet know at this stage whether DLT has the ability to revolutionise markets, it proposes to offer something new and, therefore, warrants further investigations [23].

In a public network, anyone can access the ledger; in a private network, people need to be granted access to participate [24]. Blockchain technology operates across a decentralised P2P network; it is immutable once chained; it has an algorithm ensuring all nodes have the same version of the blockchain; it is a public ledger of transactions; it uses a Proof-of-Work mechanism to validate transactions; in the case of Bitcoin, there is a mathematical and deterministic currency issuance mechanism [15], [25]. Each user has a unique public key made up of an alphanumeric string of 27 to 32 characters that makes it almost impossible to identify the individual it belongs to so, while it is not anonymous it is pseudonymous [26]. By design, it is secure and uses cryptography and a distributed consensus mechanism to offer 'anonymity', persistence, auditability, resilience and fault-tolerance [24].

Upon creation of a new transaction, the details are broadcast to the network for validation and verification, that is, to "run predefined checks about the structure and the actions in the transaction" [27, p. 763]. If a consensus is reached (i.e. agreement from more than 50% of nodes) that the transactions in the block are valid, the block is appended to the blockchain and each node's copy of the blockchain is updated accordingly [28]; it will remain there forever and is considered immutable. In a public blockchain, it is not impossible to change an existing block but it is very difficult because all blocks thereafter must also be changed as each block contains a hash of the block before it and this will be visible to the entire network [29]. Moreover, this must be done in the time it takes to mine one block to the blockchain by the network [30]. As all nodes have a complete copy of the ledger, it is very easy to see by comparison if any block has been tampered with. For changes to a private blockchain, all nodes on the network need to agree by consensus (typically off-line) and then modify the data. All blocks are linked all the way back to the genesis block ensuring the blockchain's integrity [31]. Data privacy is stronger in a private blockchain due to access rights [24]. The blockchain architecture is constructed such that malicious attacks are difficult to achieve. They require significant computational power and simultaneous access to each node to be successful [1].

2.2 Smart Contracts

The concept of smart contracts, conceived in 1994 [29], is a computerized transaction protocol that executes the terms of a contract [32]. The general objectives of smart contract design are to satisfy common contractual conditions (such as payment terms, liens, confidentiality, and even enforcement), minimize exceptions both malicious and accidental, and minimize the need for trusted intermediaries. Related economic goals include lowering fraud loss, arbitration and enforcement costs, and other transaction costs [32]. Smart contracts are considered a key influential development that will support Britain's achievement to becoming a digital economy as set out in the government report - Digital Built Britain (HM Government, 2015) [3]. Late and missed payments is a top issue within the construction sector resulting in cash flow problems, businesses failing and/or major disputes [2], [33]. A smart contract has the ability to embed funds into the contract to protect contractors, subcontractors and other supply chain actors from insolvency [33]. Combining smart contracts with cryptocurrencies has the potential to ensure guaranteed payments to an extent never before seen in the construction industry [2]. These developments are expected to have impact in areas where finances are involved and where there are time lags with regards "processes, speed of settlement, risk of fraud, back-office costs or operational risks" [34, pp. 180–181].

Due to the resources required to set up a smart contract (i.e. time and cost), Boucher *et al* [35] suggest that they are best used for repetitive agreements and not one-off complex agreements, particularly where the contract is susceptible to change throughout the life of the contract. Once a smart contract has been coded and embedded into the blockchain, it becomes permanent, unchangeable and irrevocable [16]. In the event mistakes or vulnerabilities are written into the code due to lack of legal knowledge of the coder or simply human error, once the contract is uploaded to the blockchain it becomes unchangeable and will be executed exactly as it is coded [35]. However, smart contracts can be cancelled and replaced with new ones once they have been uploaded to the blockchain [36] demonstrating some flexibility, but this would require consensus to be actioned.

Longevity is another potential issue of smart contracts. Coding smart contracts today to be executed in many years (i.e. wills or futures) is a challenge, particularly when external information sources may no longer exist [16]. In addition, cryptocurrencies are currently extremely volatile with respect to value and exchange rates against fiat currencies [26]. Ethereum, running on the Bitcoin Blockchain, is the most widely used smart contracts platform [37]. Like the Bitcoin Blockchain, Ethereum works on a Proof-of-Work protocol. Execution fees (called 'gas' and paid in Ether by the user) give incentives to miners for participating in the network. Users set the price they are willing to pay for their code to be executed and miners accept to execute the code based on that price. Execution fees deter adversaries from bombarding the network with time-consuming computations resulting in denial-of-service. While it is not impossible to do this, it is not economically viable because the gas associated with such an act would make it uneconomical [37]. One of the newest smart contracts platforms in development is NEO that proposes to provide solutions to throughput and latency, interoperability and be resistant to quantum attacks [38].

3. Findings from the systematic literature review

Three research questions were devised for this research: (1) Where is the research currently focused on application of distributed ledger technology in the built environment?; (2) To what extent is the socio-technical system of distributed ledger technology considered in the current body of research?; and (3): What are the biggest challenges the built environment is facing in implementation of distributed ledger technology? These questions were answered using a systematic literature review while adopting a socio-technical system design (STSD) approach. STSD is an approach to design that considers human, social and organisational factors, as well as technical factors in the design of organisational systems" [39, p. 4]. In addition to identifying the application of blockchain in the built environment, an emergent framework summarising the challenges and opportunities from multiple dimensions (social, technical and political) was developed.

From the initial searches in three databases (Scopus, ScienceDirect and Web of Science), 534 papers were returned. After removal of duplicates and application of inclusion and exclusion criteria within the databases, 131 papers remained. Abstracts for these papers were reviewed and 32 selected for review. In addition, further searches were conducted in Google Scholar following a more traditional route and an additional 21 papers were added resulting in 53 papers being reviewed.

Seven categories of blockchain applications in the built environment were identified: smart energy; smart cities and the sharing economy; smart government; smart homes; intelligent transport; Building Information Modelling (BIM) and construction management; and business models and organisational structures. The distribution of applications within the papers reviewed (Table. 1) demonstrates how quickly the energy industry has embraced distributed ledger technologies. Most of the papers in this category provide some element of prototyping or proof-of-concept demonstrating that the research community is developing cutting-edge technologies to exploit it.

Blockchain discussions in conjunction to BIM and construction management were found in 9 papers. However, these papers mainly provide a number of hypothetical use cases for DLT in construction but are lacking in empirical research to support those hypotheses.

Table 1. Categories of blockchain applications in the built environment

Category	No. of papers	References
Smart Energy	19	[12], [40]–[57]
Smart Cities & the Sharing Economy	6	[28], [58]–[62]
Smart Government	7	[21], [35], [63]–[66]
Smart Home	4	[67]–[70]
Intelligent Transport	5	[71]–[75]
Building Information Modelling (BIM) & Construction Management	9	[1], [3], [7], [8], [15], [16], [33], [76], [77]
Business Models & Organisational Structures	5	[25], [34], [35], [78], [79]

DLT in smart energy is changing the energy market by opening it up to allow individual homeowners who produce their own renewable energy the opportunity to trade with Major Power Producers (MPPs) through the smart grid and/or directly with their neighbours through the use of DLTs and microgrids. These prosumers generate competition in the energy market by offering alternative energy choices, which, as a side effect, is encouraging proliferation of renewable energies. Moreover, they are supporting demand response management through offering additional sources of energy that were not available previously. Different models and architectures have been proposed for the implementation of blockchain depending on the aims and objectives of the research for smart energy ranging from implementation of new cryptocurrencies and tokenisation models as incentives to trade or as currency for energy (i.e. NRGCoin) [48], through resource management using serious gaming [55], to development of end-user mobile applications integrated with DLT to make the technology more user-friendly for the general public [53].

Closely linked to smart energy are smart cities, smart homes and smart government. These concepts are not new per se but they are constantly under development as technologies evolve and understanding and acceptance of these technologies proliferates throughout society. A key concern across these areas is the security and privacy of data; something that DLT addresses in some respects but not entirely. Any data uploaded to a blockchain is considered to be immutable (unchangeable and everlasting) which removes people's right to be forgotten [80] but alternative approaches to address this concern are being considered, particularly in smart government. For example, government records can be stored off the blockchain but pointers that they exist and where to find them are put onto the blockchain. Key issues raised with regards smart government are interoperability, longevity, accessibility and balance of power [21], [63]. Interoperability is important as records produced today should be accessible and in the right format for many years into the future. While internet connectivity, both high-speed broadband and mobile networks, has advanced significantly in recent years, there still remains a large portion of the population without reasonable connectivity – only one in seven people has access to the internet in the world's least developed countries [81]. Central governance is inherent in society and blockchain technology aims to disrupt that entirely whether it be through revolutionising the finance industry by removing the need for banks or through changing the role of governments [21], [82]. Organisations and roles within them will change with the introduction of wholly automated and semi-automated organisations [16]. Corporate hierarchies will become much flatter and many roles will disappear entirely with new ones coming into being.

Also residing under the umbrella of smart cities is intelligent transport. This is already in operation in many major cities and arterial roads throughout countries, for example, through traffic calming and route variations to avoid congestion and improve air quality. Like in smart energy, blockchain technology and innovative technology companies (e.g. La'zooz) are opening up markets in the transport industry where vehicle owners now have a platform on which to monetise their idle vehicles or offer ride sharing to people travelling in the same direction [75]. This crosses over into the sharing economy where communities are able to devise and utilise proprietary value systems for sharing information, products and services resulting in a more user-led and user-empowered society [47]. The challenges and the opportunities facing the identified blockchain applications specific to the built environment are summarised and discussed in the next section. More generic challenges and opportunities have not been discussed here.

4. Challenges facing adoption of blockchain technology in the built environment

Ensuring the legitimacy of data uploaded to the blockchain about a good or service is important. Means and rules for ***authentication of data*** need to be developed to ensure predefined conditions are met to reduce the probability of fraudulent activity throughout the supply chain [34].

Sufficient ***bandwidth and capacity*** are required for stability of the system [80], [83]. Reliable internet connectivity is required, or means of storing data offline until connectivity can be achieved to ensure data can be uploaded to the blockchain in a timely manner. For example, elements of the supply chain delivery system could cause problems for instance when a warehouse lacks internet connectivity [83].

Coding of smart contracts is key, where a badly programmed contract could be disastrous [51]. Human error could also pose problems with creating smart contracts in construction given that the code is only as good as the person writing it [36].

There is a negative stigma surrounding Bitcoin and, therefore, blockchain technology with regards ***criminal activity and the Dark Net*** [26], [80]. Cryptocurrencies could be used in construction projects to finance criminal activity through money laundering and corruption [1].

One of the biggest social and environmental concerns regarding blockchain technology is its ***energy consumption*** required to satisfy the Proof-of-Work protocol resulting in excessive requirements of computational and electrical power [51], [80]. Excessive energy usage has massive impacts on the built environment with regards CO_2 levels, current grid capacities, and peak demand management [51]. Any application in the construction industry where cryptocurrencies and tokenisation are proposed is likely to have a long lead time given the extreme ***exchange rate volatility*** seen with cryptocurrencies today [84]. For example, in 2017, Bitcoin fluctuated between $1,000 on New Year's Day to almost $20,000 on 17th December only to drop by 30% in the days following [85].

Interoperability, currently considered a key challenge in construction [33], will also be a key issue for blockchain where requirements differ from one application to another. A blockchain access layer is proposed to integrate different blockchains and offer application-specific functions [28], [80]. With lack of regulation surrounding blockchain technology, it is important that risks and responsibilities be set out in a written contract.

The key ***legal concerns*** include: allocation of risk, scope of obligations, scope for variations in the contract, grounds for termination of a contract, standardisation of processes and terminology, ownership/intellectual property rights, confidentiality/data protection, corruption/bribery, appointment of a legally-recognised entity to bear responsibility of automated actions [86]. Consideration should also be given to the "parties' rights to claim additional costs, time and, in the case of NEC contracts, compensation events" along with "[w]ho bears the risk should they result in delays or increased costs to the project?" Finally, what happens to the blockchain in the event of insolvency and/or termination? [87]. Dorri *et al* [67] highlight seven types of ***malicious attacks*** as follows: 1) accessibility threats; 2) anonymity threats; 3) authentication and access control threats; 4) Denial-of-Service (DoS) attacks; 5) modification attacks; 6) dropping attacks; and 7) appending attacks. Eyal [88] discusses block withholding attacks in mining pools. A 51% attack is where a miner tries to take control of the system by controlling more than half of the network and revising transaction history or preventing new transactions from being validated [28], [56], [67], [89]. Other types of attacks exist where a miner or a pool of miners attempt to control and compromise the system (see for example, [37]). Personally identifiable data or the potential to gain financially (i.e. theft of cryptocurrency) from a smart city is attractive to a potential attacker [68].

There is agreement with regards ***readiness for adoption*** of DLT in the construction industry particularly with it not being ready for the level of collaboration and information exchange required for it to be successful [1], [76]. The construction industry is typically slow at adopting new technologies [1] and historically ***resistant to change*** which could result in less benefits being realised by the implementation of DLT [84]. There is a current lack of ***sufficiently skilled people*** trained in blockchain technology [80]. Even organisations looking to embrace BIM struggle to recruit suitably skilled personnel [76]. The ***technological state of the construction industry*** is not sufficiently digitised to take full advantage of DLT and implementation of this new technology is likely to be costly [84].

5. Opportunities from adoption of blockchain technology in the built environment

Lack of trust and limited collaboration between parties is one of the frequent issues cited in the construction sector that is also affecting BIM adoption [90]. Due to data becoming more transparent, ***increased collaboration and trust*** between parties is likely and data will be shared more freely [87]. Tokenisation through cryptocurrencies (i.e. ConstructCoin) could encourage data sharing where contributors are rewarded for information they generate and could gain more if/when that data is bought by a client [84]. Reputation ratings on DLT is a potential booster for increasing collaboration throughout the supply chain, for example, promoting strategic partnerships [76]. Particularly where cryptocurrencies are involved, ***cross-border trade*** can be made easier without the need for international exchange rates and border controls. However, this has the potential to interfere with the current international economic order [65]. Where [sub-]contractors are based in countries other than where the client/project is based, blockchain with suitable cryptocurrencies can mitigate exchange rates and fluctuations in currencies [1].

DLT can be used for ***digital twinning*** of built assets providing valuable detailed information throughout the lifecycle of an asset where all information related to that asset from inception to decommissioning is recorded and available for facilities management, buyers/sellers, surveyors, demolition teams etc. [36]. This is in line with other technological advancements such as IoT, drone and real-time data capture technologies that support digital twinning and improving ***building operation*** [84]. The distributed nature of blockchain technology removes the requirement for intermediaries and provides a guarantee of execution of transactions [47]. Smart contracts can be used to automate payments upon successful inspection of a completed task by a subcontractor through if/then commands and payments can be made in cryptocurrency further speeding up the process [84].

Disintermediation means clients will have more control over their projects with regards costs, time and scope [91]. Blockchain can also promote ***efficiency*** in international business-to-business trade and increases access to trade and supply chain finance [80]. In addition, automation of activities within construction leads to reallocation of resources reducing administration activities as well as transferring risk and reducing time and costs [76]. ***Faster processes*** through streamlining verification will reduce the need for multiple verifications by different participants where the relevant information is stored on the blockchain, particularly in functions such as planning and design of construction projects [36]. Costs for intermediaries is eliminated ***lowering transaction costs*** [47], [80]. Efficiency is increased in international payment systems; friction and costs of property registration is reduced [80] resulting in lower costs for the client [1].

While not technically ***immutable***, blockchain technology is considered as such due to the difficulties involved in changing transactions and/or blocks already uploaded to the blockchain [47]. In construction, a historical record is essential for activities such as "timestamping acts or transactions, Multisignature Transactions, Smart contracts…and Smart Oracles which are real work depositories of information to be used in conjunction with smart contracts" [15, p. 642]. ***Proof of ownership and rights*** issues can be addressed using blockchain technology due to the advantages of cost, speed and double-entry bookkeeping in terms of providing proof-of-ownership for many different assets from real estate to vehicles to art and stocks and bonds [30]. In construction, where ownership and rights are a legal issue [15], and in the event of a single [shared-access] BIM model, ownership and rights (i.e. responsibilities, liabilities, intellectual property rights) can be made explicit in the blockchain leading to better trust between parties [77].

Proof-of-Provenance will be much easier to obtain through DLT [92]. DLT has the potential to provide better record keeping through a traceable, seemingly immutable ledger allowing investigators to immediately pinpoint where problems occurred in the supply chain and possibly prevent problems such as Grenfell Tower from taking place as people are held more accountable for their actions through increased transparency. DLT will allow tracking of goods and services throughout the supply chain offering near real-time data as well as provenance history [93].

A ***reduction in human error*** will be seen through the automation of tasks, the use of sensors and/or artificial intelligence and smart contracts. Certification and/or verification of coding through DLT would provide quality assurance for construction projects [36].

Through ***smart contracts***, many tasks can be automated and entire legal contracts can be written into code changing how organisations operate, speeding up payment of funds embedded into smart contracts, help to reduce disputes etc. [2], [32], [33], [35]. Construction is notorious for its number of disputes, particularly regarding payments. Blockchain could operate as a "trustworthy contract administrator by introducing an error-free process based on which the contracts would be both built and monitored" [84].

Its nascent nature means the technology will advance significantly in coming years and it is likely that it will evolve into a solution that puts ***societal benefits*** at the centre rather than the technology [82]. Smart buildings and smart contracts in conjunction can add benefit to society through extending asset lives and ensuring timely repairs are scheduled based on performance, occupant behaviour, energy requirements though quantitative data analysis ensuring continued learning and improvement [76].

Blockchains provide ***traceability and auditability*** through an "immutable" historic record [21]. Koutsogiannis and Berntsen [84] believe it can "add more transparency to every type of agreement and transaction in a construction project". Supply chains become more visible and allow real-time tracking of materials to a construction site providing a history from origin [94]. Finally, blockchain indirectly contributes to ***improved workflow*** through contributing to creation of more open project environments**.** This opportunity is linked to the role blockchain can play in increasing collaboration and transparency and improving accountability and project control. BIM technology uptake may increase as the need for peer-to-peer information sharing increases [84]. If these peer-to-peer exchanges are within workflows supported with smart contracts, the waiting time for 'sign-off' would be eliminated as *input* for the completed task would be followed by an automatic *forward* to continue to work [95]. This will positively impact on the schedule performance of construction projects.

4.3 Emergent Framework

The emergent framework for blockchain implementation within the built environment is depicted in Fig. 1a. It combines three interconnected dimensions, namely the political, social and technical dimensions. The framework is overlaid with the challenges and opportunities (Fig. 1b,c). Challenges and opportunities will reside within one dimension, across two, or at the overlap of all three in the centre. The extensive list of challenges and opportunities identified within this review were all embedded within the framework according to their classification (technical, social and political). The framework's dimensions are also used to identify the agents pertinent to each challenge and opportunity who may play a role in either facilitating or impeding the adoption of DLT in the built environment.

The ***technical*** dimension is concerned with the implementation of the technical architecture of DLT. Many of the challenges highlighted at this stage in the technology's development (e.g. throughput, latency and interoperability) are likely to be addressed over time with updates and as new products become available. For example, NEO is an example of a DLT that is already attempting to address many of the technical challenges. Agents involved in this dimension include but are not limited to developers, system architects and nodes (computers running on the P2P Network).

The ***social*** dimension is associated with the impact DLT will have on the society and is broad reaching in terms of the agents associated, which include, but are not limited to individual users, social groups and organisations operating within the built environment generally and construction projects particularly. This dimension addresses how the technology will integrate into the real work and represent the social system where benefits of DLT adoption will occur and the agents who will benefit from its adoption. At this early stage of the development of the framework, an 'holistic social' dimension is adopted as the focus is on exploring the opportunities and challenges for the whole built environment. For the future development of the framework and to improve its applicability to project level, a consideration will be made to add a 'process' dimension that is now inherently embedded within the social dimension.

The ***political*** dimension represents the environment in which DLT will be established and the interactions /influences that agents from the political field exert on DLT adoption. This includes establishing robust regulations, laws and compliance for implementation of DLT in the built environment and the construction industry. Agents for this dimension include, but are not limited to governments, authorities, DLT councils (i.e. those with the power over how DLTs function) and other organisations/individuals in governance positions.

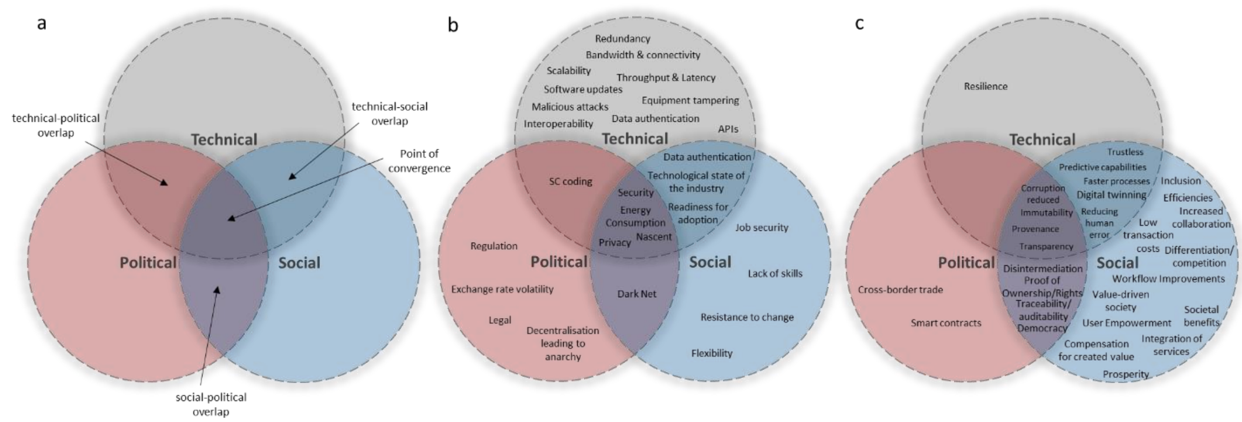

Fig. 1: (a) emergent framework for blockchain applications in the construction industry; (b) framework overlaid with challenges; (c) framework overlaid with opportunities

6. Conclusions

This paper aimed to (1) capture the current state-of-the-art of DLT research for built environment applications; (2) understand the challenges and opportunities associated with the adoption of DLT in the built environment; (3) to develop an emergent framework for DLT adoption in the built environment. A systematic literature review driven by a socio-technical system design (STSD) approach was used to address the first two aims. An inductive research approach underpinned the inquiry process and culminated with the development of the emergent multi-dimensional framework.

DLT applications were found in several areas including: smart energy; smart cities and the sharing economy; smart government; smart homes; intelligent transport; Building Information Modelling (BIM) and construction management;

and business models and organizational structures. Within the built environment, most applications are focused on the operation phase of assets. DLT empirical evidence and technological developments exist across most of these areas with the exception of BIM and construction management where research is either limited to proposing hypothetical case studies or focused on smart contracts. An extensive set of challenges and opportunities facing the adoption of DLT in the built environment were identified and explained.

An emergent multidimensional framework for blockchain adoption within the built environment was developed. The framework combined three interconnected dimensions consisting of the political, social and technical dimensions. The framework was overlaid with an extensive set of the challenges and opportunities facing the implementation of DLT in the built environment. This framework represents an important baseline for DLT adoption in the built environment. Field researchers can utilize it as a point of departure for a wide range of investigations from political, social, and technical perspectives.

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Lunar construction solution: Chinese Super Mason

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Abstract

Supporting the goal to develop the habitat for people to work and live safely and sustainably on the moon, the Lunar construction robot is typically designed with 3D printing system based on laser sintering technique with Lunar soil. Huazhong University of Science and Technology *(HUST)* propose a novel robotic system for Lunar construction entitled ***CSM: the Chinese Super Mason***, combining on-site prefabrication of bricks and arch segments with Lunar soil and multi-structural automated assembly processes. CSM consists of a compound fabrication system composed of 6-axis robotic manipulator and automated sintering fabricator carried on an autonomous limbed vehicle platform. As a case study, a 2.8-m-long, 1.6-m-wide prefabricated structure for Lunar Base was successfully assembled with an experimental platform. Benefits and limitations of CSM and its experimental platform were identified and analyzed. Finally, prospections and exploratory steps toward the future of Chinese Lunar Base are also discussed along with the proposed CSM applications for Lunar construction.

Keywords: Lunar construction; Robotic construction; Prefabrication; Automated assembly; Chinese Super Mason

1. Introduction

With the rapid development of society, the exploration of the living space of mankind has been continuously expanded and deepened to the extreme environment area that is inaccessible. These extreme environmental areas mainly include two types: one is the area beyond the Earth's terrestrial surface such as deep space, deep sea and deep earth, and the other is the special terrestrial land surface such as polar areas, nuclear pollution and major natural disaster sites. In order to support human exploration of extreme environment, new special buildings and structures will emerge, and existing engineering construction theories, methods and techniques will not be applicable in the extreme environment where human beings find it difficult or impossible to reach. Unmanned construction is bound to be the only effective way of building an extreme environment.

For half a century, the exploration of the deep space has been progressively pushed forward by human beings. As early as the 60s of the last century, the United States and the former Soviet Union, based on the purpose of military competition, carried out a great deal of exploration on the moon and successfully implemented a number of plans and in the end stopped them. At the beginning of this century, the United States has restarted explored Mars and even the outside solar system. In recent years, Europe, China, Japan, Korea and India are all involved in the lunar exploration. The construction of the Moon Base has become a great concern of this century.

The research on the construction of the lunar base mainly includes six aspects, such as environment simulation, material preparation, site selection and site planning, architecture design, construction technology, support technology and so on. The first part of this article describes the urgency of the research on the construction of the moon base. The second part introduces the related research at home and abroad. The third part describes our Chinese design of the lunar bas, and is simulated and verified in the fourth part. The fifth part makes a prospect and summary of future research.

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2. Related research

In 2013, NASA proposed that the use of high power laser will be lunar basalt weathering layer and high temperature sintered glass like material, build a lunar base using 3D printing technology[1]; at the same time, NASA designed a multi legged robot platform corresponding to the moon, collecting raw materials, in the process of the construction preparation and construction[2]. In June 30th, 2017, the United States re-established the National Space Committee, which is directly subordinate to the Executive Office of the president. On October 5th, former vice president Mike Burns officially announced that the United States will restart the lunar landing plan. In terms of ESA, in 2014, the lunar basalt weathered rock powder was used as raw material and the binder was solidified by high effective adhesive. The honeycomb wall arched Moon Base was prepared by using the "D-shape" 3D printing technology[3]. KAKI has long been committed to the research of cementing lunar soil with thermosetting polymers, and has collaborated with NASA to carry out 3D printing technology for polymer bonded lunar soil. India Institute of Physics developed a metal container pressure and temperature controllable conditions, used to simulate lunar extreme environment[4]. The following are six aspects of the lunar construction:

2.1. Environment simulation

India, the United States and other countries adopted the experimental simulation and numerical simulation to study the temperature changes of the lunar surface. The India Institute of physics has developed a metal container system that simulates the pressure and temperature conditions of the surface of the moon, the system can achieve some special pressure, and can keep the temperature of the sample in the daytime and night temperature of the monthly table, respectively[4,5]. The University of Connecticut established a general equation based on the thermodynamic principle of thermal flow. The thermal flow environment of the moon and below the monthly table were analyzed to determine the gradient of temperature with time and the depth of the moon and the analysis of the 1 meters of the moon rock wind outside the base of the base structure, the detailed temperature characteristics of the soil protection layer[5].

2.2. Material preparation and site planning

The Hanyang University and University of New South Wales have made use of simulated lunar soil as the main raw material to prepare lunar construction materials by sintering, bonding, dry mixed pressure, and geological polymerization[6,7]. Based on the constraints of lunar environment, the United States and France have studied the location of lunar bases and the planning of base construction sites. The site plan of the moon base proposed by University of Southern California, including landing pad, connecting land location and base passageway, and transportation system[8]. The French International Space University has proposed the overall infrastructure and site layout of the "LB10" moon base, including the spacecraft landing field, the launching station, the power station, the base building and the scientific telescope[9].

2.3. Structure design and construction technology

The United States, Italy and other countries have studied the architectural design of the lunar base[10,11,12], which can be divided into three categories, including: 1) inflatable structure, 2) rigid structure, 3) mixed structure. The United States and ESA have studied it. From the point of view of material sources, the current construction technology of the lunar base can be divided into two categories, including: 1) the earth's raw materials, transport to the moon 3D printing robot, 2) the moon on the ground, and the 3D printing robot.

3. Conceptual design

3.1. Overall plan of the scheme

In this paper, we proposed a CSM application for the Lunar construction. We will build the theory, method and technology of the unmanned moon base in the whole process of Perception - Decision - Design - Construction - Operation and maintenance of special structure, material and performance. The CMS includes two core parts: robot operating system and program execution setup. According to the automated construction path optimization algorithm, robot operating system could convert the Building Information Modeling (BIM) model into a series of coordinates that the robot could match with different path (Fig. 1).

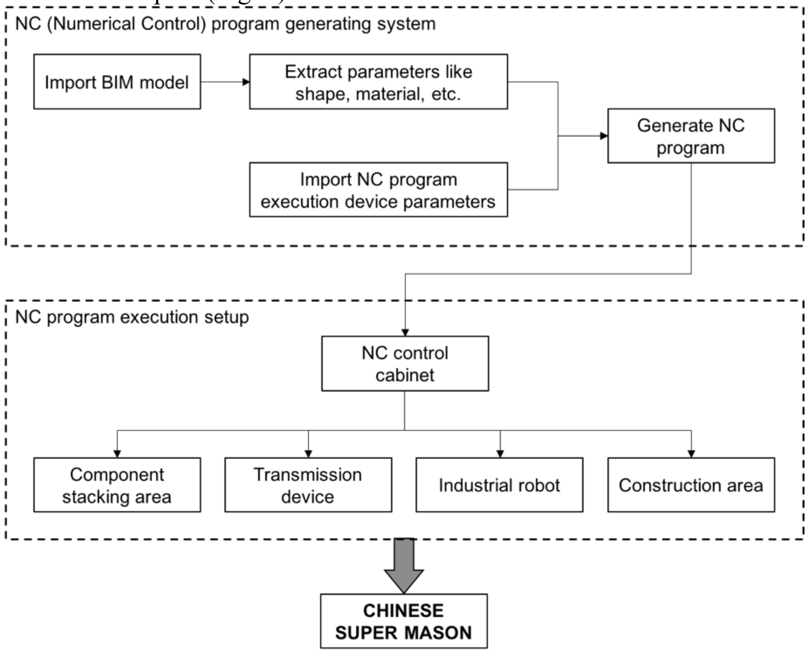

Fig. 1. Composition diagram of CMS

3.2. Conceptual design

The main function of the moon base is to achieve temporary or permanent base facilities in the lunar environment. During the construction of the lunar base, the moon environment, such as gravity, air pressure, temperature and earthquake, should be taken into account. The moon is rich in lunar soil and lunar rocks, and the compressive strength and tensile strength of lunar rocks are 10 times that of the earth. Therefore, the use of local materials, the construction of practical structure, modular, light construction equipment.The scheme to reduce the cost of launch and launch is more appropriate.

According to the international principle of building "local material" for the moon base and the design of the arched structure of the ground base, we compare the following four possible construction schemes for the 3D printing robot of the lunar base: 1) NASA's laser layer by layer sintering method for lunar soil accumulation; 2) Formation of adhesive bonded layer by layer bonding method for lunar soil consolidation in ESA and other agencies; 3) Layer by layer extrusion molding for microwave melting of California Institute of Technology; 4) Laser sintering masonry of lunar soil blocks at Huazhong University of Science and Technology, China.

	Indicator	1	2	3	4
Raw material system	Complexity of raw materials	★	★★	★	★★★
	Lunar soil utilization	90~100%	70~80%	90~100%	80~100%
Technical equipment	Equipment complexity	★★	★	★★	★★★
	Technical maturity	★	★★	★	★★★
Construction process	Energy requirements	★★	★	★★	★★
	Construction efficiency	★	★★	★★	★★★
Application performance	Material and structural strength	★★	★	★★	★★★
	Durability	Further study			

Fig. 2. Comparison of base construction schemes

From the above table (Fig. 2), the " Laser sintering masonry of lunar soil blocks" scheme has high technical maturity (long history masonry), high construction efficiency (large scale layer thickness), good strength of material and structure, and is proposed as a proposal, named " ***CSM: the Chinese Super Mason*** ".

3.3. Construction equipment

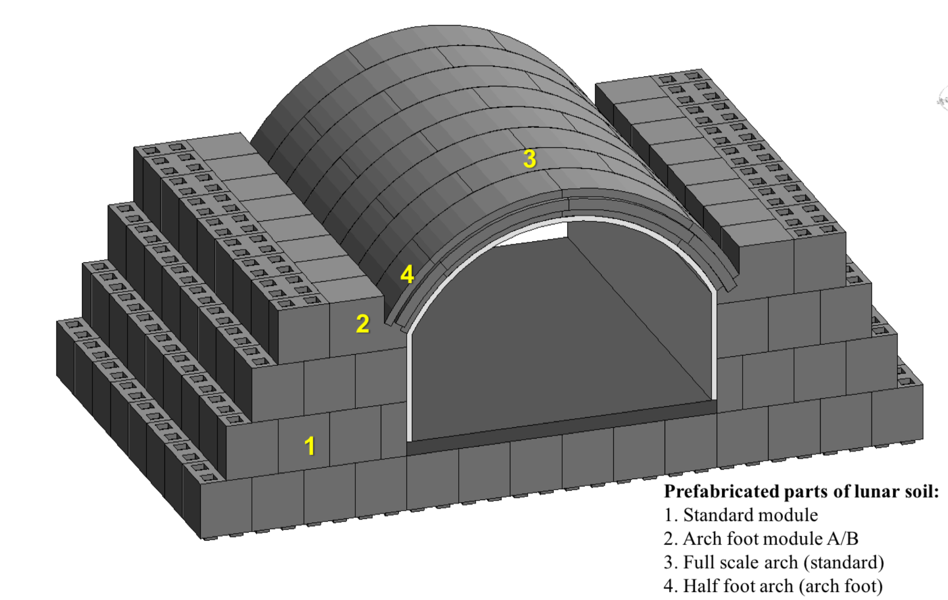

Fig. 3. Structure scheme of lunar loam module arch

In view of the above recommendation, we designed the structure scheme of lunar loam module arch (Fig. 3). The construction plan of the lunar base is characterized by the establishment of an integrated construction system and matching of different construction tasks. The core of the technology comes from three aspects: 1) design and manufacture of the acquisition module for raw materials (lunar soil); 2) design and manufacture of terminal modules for carrying out construction tasks (masonry, sintering, melting, etc.); 3) design mobile robot platform suitable for lunar environment and develop adaptive technology.

4. Simulation: the Chinese Super Mason indoor

4.1. Model design and construction preparation

In view of the plan design in the third chapter, we simulated the experimental scene in the laboratory. The execution setup consists of a component stacking area, transmission device, industrial robot and construction area (Fig. 4).

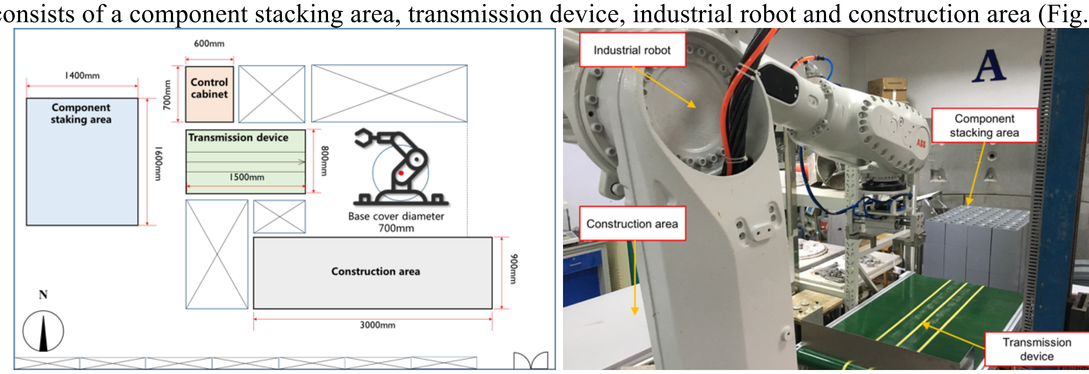

Fig. 4. NC program execution setup of CMS

In the staking area, each component has a code which follows the construction order that we have optimized in the BIM (Fig. 5a) and the tramsmission device (Fig. 5b) delivers the component to the industrial robot (Fig. 5c) which is controlled by the control cabinet (Fig. 5d) to catch the component with the functional fixture (Fig. 5e) to the construction area (Fig. 5f).

The related parameters of some machines of the NC execution systems are listed as the following:

- The industrial robot and the control cabinet are the ABB IRB 6700-235, whose movement of the arm is 2.65m, 235kg load and 0.05mm repeat positioning accuracy.
- The transmission device is 0.8m high, 1.5m length and 0.8m width, over 8kg weight nagative, 1m/min minimum speed and 5m/min maximum speed.
- Functional fixture is drived by a MHL2-40D cylinder with the same size of the component.

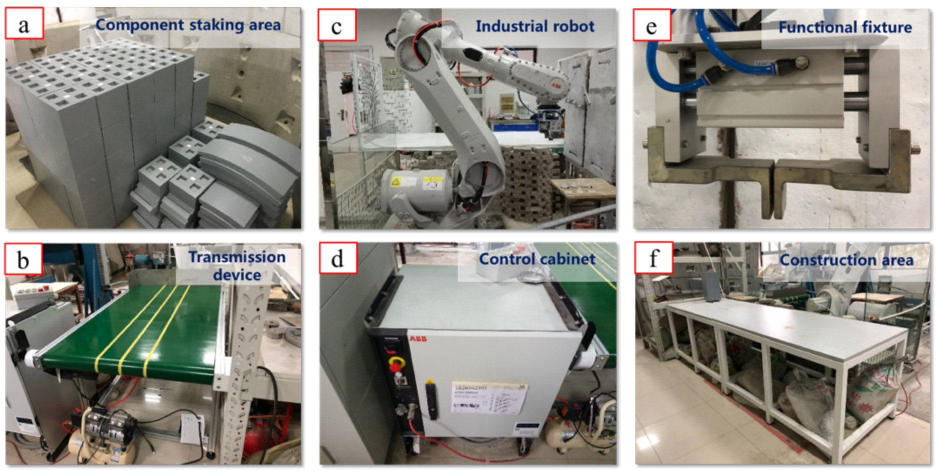

Fig. 5. Distribution composition of CMS

4.2. Module design and production

As we all know that most of the moonbase has an arch structure which has a good performance in high strength and shockproof. In Chinese traditional bridge structure, stone arch bridge is pretty universal. According to this, we design the Chinese Super Mason (CMS) plan which is a prefabricated assembly structure consisting of six diferent basic elements, 8.0m high, 14.0m length and 8.0m width. Because of the limitation of site condition, we manufactured these six different components reducing the size of 5 times, 150 in total. Comparing three construction sequences in Naviswork, we choose the plan A down to top (Fig. 6) to implement in our case study.

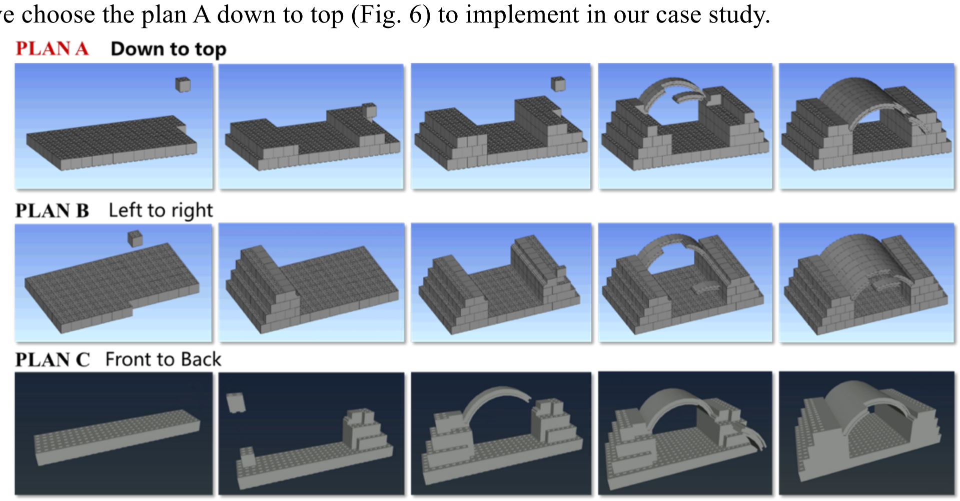

Fig. 6. Simulation of the construction sequence

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4.3. Automated construction process

For the construction path optimization algorithm, we designed this from one feeding palce where the transmission device work and changeless to different construction point. The coordinates of these points we have calculated before will be compared to these we got from the process simulation of the robotic Moon Base construction using the teaching apparatus. We use the ABB programming language having a good encapsulation to control the robot (Fig. 7).

Fig. 7. Construction process of the Moon Base

5. Future directions and conclusion

Prospections and exploratory steps toward the future of Chinese Lunar Base are discussed along with the proposed CSM applications for Lunar construction in this part.

- New construction material. The biggest problem for automatic construction technology to face with is the material problem. The next step, we will use the automated sintering fabricator technology to manufacture the simulated lunar soil components.

- Accuracy issue and new fuctional fixtrue. There are many factors affecting the accuracy of automatic construction, mainly including site layout, design of the fuctional fixture, location precision of components, etc. Wherein the design of the fixture is one of the most important problems, or rather, the more meticulous the fixture, the higher the accuracy, yet the lower the construction process speed at the same time. Therefore, it needs to take comprehensive consideration of the accuracy and speed of construction to set proper fixture size.
- Algorithm development and process control. Optimized construction sequence algorithms are critical in that the time of machine running can significantly be reduced. This paper provides some simple robot moving algorithms, which may cause time waste due to many invalid paths. So the optimization of the construction sequence algorithms is very important. Furthermore, the development of hierarchical algorithm of BIM model is also important to reduce manual operations and improve the efficiency of NC programs. CMS provides a good foundation for multi-equipment collaborative construction and the next step is to design a fuctional fixture for different components corresponding to construction sequence.

The further research about Lunar Base construction is presented above. While still in its prospections and exploratory, this research has the potential to improve the traditional automatic construction methods, and solve problems like high accident, low quality, loss of skilled workers, and so on.

In the case of construction equipment, construction of artificial intelligence technology, advanced manufacturing technology, and other digital technology research provide technical support for the development of equipment in extreme environments and possible major scientific technical breakthrough in the field of special unmanned equipment. Lunar construction in extreme environments as a subversive construction model to devote to the new construction organization plan and management model will greatly expand, enrich and reform the construction management theory and method.

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Process information modelling (PIM) for public housing construction project in Hong Kong

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Abstract

Public building construction, which consists of many sub-tasks and numerous systematised working processes such as planning, mobilisation, scheduling, procurement and controlling, is complicated. If the project team is incapable of managing these processes seamlessly, it may result in severe project delay and cost overrun. This issue becomes even more apparent when utilising construction robotics, since precise process and scheduling information as well as feedback is required to ensure each task is completed correctly and on time. Support in addressing these complex management activities in particular for the robotic usage offers Process Information Modelling (PIM). In this paper the process-oriented modelling approach, PIM, which provides a collaborative way of planning, designing, producing, assembling and entire project life cycle management strategy is introduced. The main objective of PIM is to integrate with the conventional Building Information Models (BIM) and supplement them with a process oriented database platform, allowing for smooth data transfer, as well as promoting seamless and constant data sharing among all stakeholders. Digital documentation, simulation and real-time data are produced progressively to support the decision-making process. The effectiveness of the PIM is demonstrated on façade painting task by a painting robot for an on-going consultancy project commissioned by the construction industry council (CIC) in Hong Kong. The impacts of PIM on supporting the potential future applications of construction robotics and instigating the next construction information evolution are discussed.

Keywords: construction automation; construction management; Hong Kong; integration; PIM

1. Introduction

For many years, many researchers have agreed that efficient integration and coordination of design, construction, and management data can potentially benefit the overall performance of the construction industry [1]. Recently, other industries are submerged with data; the construction industry is not an exception to this unprecedented trend. In each step of a construction project, the project team will be dealing with enormous data, which amongst various professions and the decisions have been made could impose serious implications on the construction project. Currently, Building Information Modelling (BIM) technologies are being considered capable to deal with multi-dimensional CAD information systematically, improve data integration among cross-disciplinary collaboration across the construction industry and between the key stakeholders.

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Even though BIM can cover the construction project span from early stages to the completion of the project, the implementation of BIM technologies is often fragmented in most of the construction projects. This is partly due to the fact that in practice BIM does not effectively categorise or integrate the most relevant data and distribute the information to the most desired stakeholder. A piece of information cannot function alone without specific protocols and relationships behind it [2]. The BIM technologies should be able to provide a platform where the data collected from each phase of the project that can be integrated as well as interoperating between various applications [3]. Therefore, the concept of the next generation of BIM is not merely just gathering information or use of several of technical tools but managing information across diverse collaboration and interrelationship of the key stakeholders. Additionally, it is essential to deliver the right information to the right place for the right people at the right time [4]. Process Information Modelling (PIM) has the potential to be developed as the next generation BIM, which will enhance information integration, yet focus on the process of each construction tasks and the relationship between each attribute. In this case, the attributes can be people, products, process or technologies. By doing so, it helps the project team to identify challenges of execution from both technological and social approach also provides feasible solutions proactively [5]. The detailed description about PIM is demonstrated in the later section.

This paper proposes a scenario in conjunction with the ongoing consultancy project commissioned by the Construction Industry Council (CIC) in Hong Kong. It hypothesises the PIM concept imperatively applied to the utilization of a façade painting robot. In general, the Hong Kong Public Housing Construction (PHC) sector faces experiences three major challenges: (1) to satisfy the increasing demand; (2) to achieve affordable price and (3) to address demographic changes. Accordingly, the CIC commissioned the Chair of Building Realization and Robotics (br^2) at Technical University of Munich (TUM) to research and develop construction robots and automation strategies that are tailor-made for the PHC in Hong Kong. The proposed external painting robot provides an opportunity to develop and validate the PIM concept. The implementation of construction robotics will trigger a series of changes in the construction sequence and potentially revolutionises the construction industry as a whole. It is the commitment to meet the challenges of the collaboration of the academia and key stakeholders to launch a significant attempt for developing a tailor-made process orientated approach on the basis of the current BIM technologies.

Although, research has been done based on the topics of BIM, yet limited research topics were conducted related to the topic of how to implementing BIM technologies when adopting robotic and automation technologies in the construction project. There are few questions need to be raised, such as, when implementing robotic and automation the operational methods and the working process will dramatically differ from the conventional way, so are the existing BIM technologies still adequate to handle the tasks? If not, is the proposed PIM concept able to tackle the challenges and how? This research forms the backbone for developing PIM applications in the future. However, due to the lack of available resources and complexity of the construction process, the PIM applications can only be conceptualised.

Consequently, the authors evaluate the current BIM and big data technologies through an extensive literature study to explore the potential constraints within each key project phases and exam how to transfer those constraints into opportunities for the construction sector and beyond. The proposed PIM concept offers a practical approach, which can be used as a guideline of how to integrate and distribute information and enhance decision-making procedures during the design, precedent and tendering, logistics, construction and facility management phases. As a result, the proposed PIM approach can yield a huge change in how the construction industry handles such large volumes of heterogeneous data as well as enhance information acquisition, integration, which provides real-time data sharing among all key stakeholders. In addition, it lays a foundation for developing a practical PIM application in the future.

2. Building Information Modelling (BIM) and Process Information Modelling (PIM)

2.1. BIM

Recently, BIM is one of the most promising developments in the Architecture, Engineering and Construction (AEC) industries. BIM became more influential within construction projects, which commonly used in the design, visualization, planning, facilities management and cost estimating purposes. Using modern modelling tools, such as Revit Architecture, ArchiCAD or Tekla Structures, the content produced by architects, designers and engineers have evolved from traditional 2D-drawings, sketches and written specifications to parametric, object-oriented 3D-models embedded with information to describe any building or facility in detail [6]. With BIM technology, an accurate virtual model of a building is digitally constructed [7]. When integrated efficiently, the computer-generated model contains precise geometry and relevant data needed to support the construction, fabrication and procurement activities involves in the project [3]. Although BIM applications claim the seamless integration of data from each project phase, in practice there is less evident how accurate and rapid the data has been passed on and how the data has been utilised. This may be resulted from the availability, compatibility and interoperability between raw data and the applications. These aspects determine if the data can be transferred, integrated and responded in real-time. On the other hand, BIM application is a knowledge-based and object-oriented approach that aims to digitally and visually represent the real world situations, in other words, it can be considered as the identical twin of the real world. This might sound unrivalled, however, when implementing construction robots or carry out a complex construction project, only understanding the real world condition is not enough. Know-how based, interactive, proactive and responsive extension of BIM is required [8].

2.2. PIM

The widespread use of digital technologies will lead huge amounts of data being generated throughout the construction process. Some of the data is well understood by the stakeholders, for instance, Computer-aided design (CAD) data, Excel data, 3D virtualizations. On the other hand, some of the other data may be less familiar to the stakeholders, and it hugely depends on their experience, background and professional field. The main objective of PIM is to make sure that everyone understands the data correctly; to predict what is going to happen in the future that based on the existing information variables. Specific actions need to be taken for analysing the risks and challenges might occur and recommending the options to the decision maker in real time [9].

PIM application is a process-oriented, case-focused approach that provides detailed information about a specific task. It then breaks down into smaller, manageable data and is distributed to the right stakeholder at the right time. The recipient can plan; react to the distributed data by following a guideline generated by PIM. The main feature of PIM is to optimize the entire construction process -rather than optimizing some parts and neglecting the others- by offering rapid, consistent data management and providing interactive, proactive, responsive data integration. In addition, it equips with cooperative and interoperable program applications that offer information, which can be understood by the stakeholders, rapidly accessible, predictive analytics as well as provides feasible guidance when issues occur [6].

In principle, PIM consists of five fundamental stages, which include Project break down, Data management, PIM Big Data (PBD) architecture construction, Implementation and PBD distribution. During the Project break down, each project stage is formulated as individual data cluster, which can be deployed, assessed, processed and transferred independently. For example, the initial data clusters shall include; design data, production data, procurement and tendering data, logistics data, rapid construction data and lifecycle management data. As a result, the data clusters are loosely coupled, they provided the database that can be categorized, classified and shared with the relevant party. The human data, physical data, project management data, facility data and cyber data will be analysed. The main goal of this stage is to differentiate and integrate the data based on the relevance of the information that evaluated by the key stakeholders. This action can potentially enhance interdepartmental, cross-functional and cross-disciplinary data interaction; therefore, it adds value throughout the project.

During the next stage, PBD is further categorised into four main databases, which are physical database, BIM database, Internet of Building Things (IoBT) database and maintenance management database. The physical database contains the information that is gathered through paper-based hardcopy documents, as well as the information, which has not yet been transferred into digital data. The BIM database covers the range of information from basic data to highly sophisticated implementations, which include 3D, 4D, 5D and 6D BIM applications. The IoBT database comprises of a range of smart data collected throughout the construction phases, which include geolocation tracking, monitoring of equipment, inventory, procurement management, quality inspection, real-time measuring and control and remote operation. The maintenance management database covers the information accumulated over repairing, alteration, conversion, upgrading, scheduling and budgeting aspect of lifecycle management activities [9].

The aforementioned data is collected and stored in the PIM data Processing Unit (PPU). PPU is not only for data acquisition but also and most importantly it is a range of interoperable applications that actively processing data in real time and analysis huge amounts of data created from a variety of sources. The main strategy of PPU is to process, integrate, transfer, share and store the real-time data. Also, it enhances collaboration and supports the decision-making activities by distributing the most relevant information to the right key stakeholders at the right time. At the time of this writing, PIM is only developed as a conceptual model that demonstrates the overall concept, yet capable of offering basic instructions and data analysis that based on the scenario created by the Hong Kong CIC project.

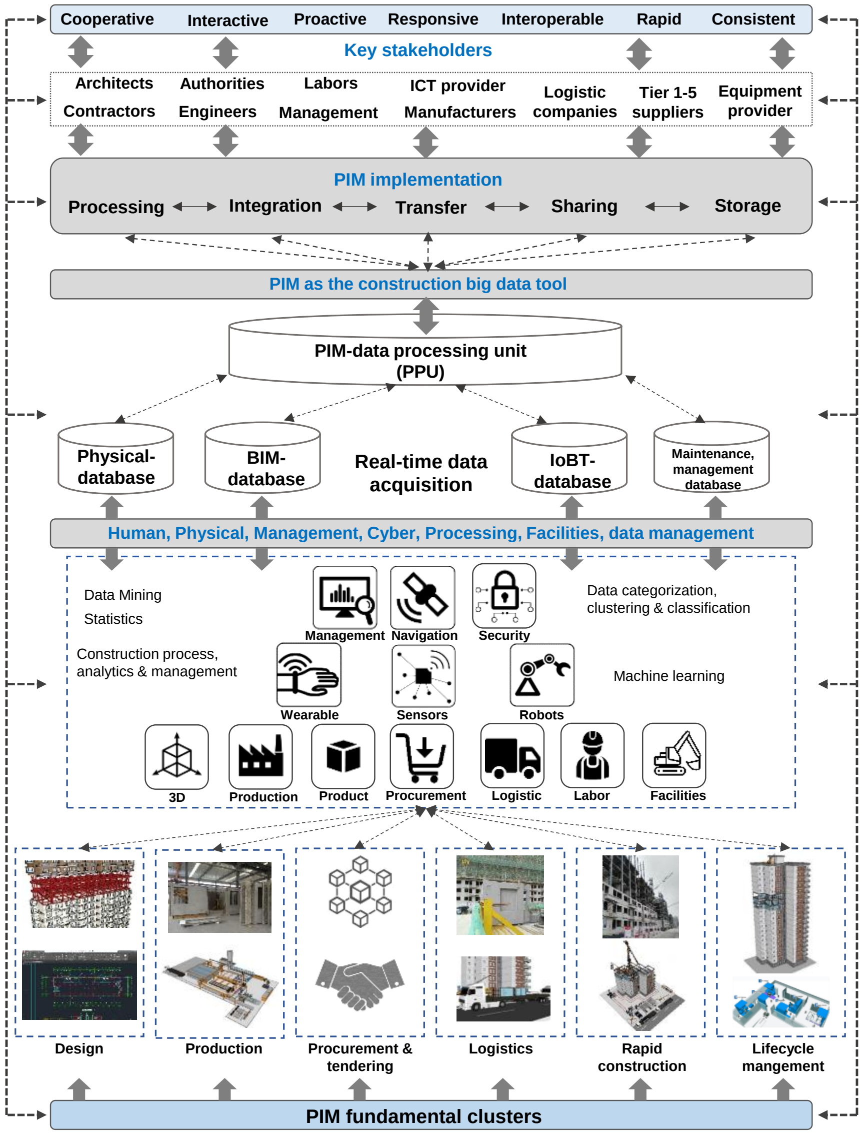

Fig. 1. Process Information Modelling concept.

3. Literature Review

The construction industry is dealing with significantly increasing data from varies disciplines throughout the construction process. As mentioned earlier, the PIM proposal can be seen as Big Data application. Utilisation of the applications can yield momentous benefits for an organization or individuals undertaking a variety of complex construction projects. In this section, the literature review and theoretical background are briefly introduced.

3.1. Big data

In general, Big Data is consists of two main activities, include Big Data Engineering (BDE) and Big Data Analytics (BDA). First, Big Data accumulates huge amount of data and then processing them by tools such as Apache Hadoop (AH), Apache Spark (AS). Secondly, Big Data storage is another crucial task, which manages whether or not the data is to be distributed or emerged.

Apache Hadoop: The AH is an open-source implementation of MapReduce (MR) [10]. It is designed for managing very large node of the data base [11] on computer clusters that constructed from commodity servers. Nowadays, many web based brands are using Apache Hadoop platform, such as Yahoo! [12] and Facebook [13].

Apache Spark: The AS is one of the many open-source cluster computing platforms for processing large-scale data. It has gained increasing popularity recently due to the processing speed and user-friendly feature. It is a fault-tolerant and optimised by Application-Programming-Interface (APIs) in interpreted high-level programming languages, such as Python, Java, R and Scala [14].

With the increasing amount of heterogeneous, autonomous parallel distributed sources and data, Big Data Analytics (BDA) has become crucial for many business disciplines. In general, BDA provides a new paradigm on how to handle, storage, manage and access to those huge datasets [15].

Starfish: Commonly, starfish is a self-tuning system used by data scientists, business analysists and IT operators to visualise, optimise as well as strategize the AH application. It builds on the AH application and adapting user's needs to achieve better performance automatically [16].

3.2. SODATO

SODATO stands for Social Data Analytics Tool that is developed to provide a generic method to gather, store, process, analyse and summarise big social data, which accumulates through the organisation's social media platforms. It provides a strategic tool that actively interacts with the big social data [17].

3.3. Program language

During the development of PIM concept, it was evident that there are various examples in computer software design, which have conceptual principles similar to those in PIM. A brief analysis is conducted to offer a reinterpretation of PIM concept by using software programing concepts [6].

Service-oriented architecture (SOA) can be described as a loosely coupled program architecture designed specifically to meet the needs of an organization [18]. By using communication protocols which provide services to another component and make connections between different software components over a network [19], the definition of a service can be viewed as a logical representation of a repeatable task. SOA is independent, self-contained, yet when combined it forms the functionality of a large software application. The unit architecture in PIM also shares similarities with the service architecture in SOA [20]. It is beneficial when linking an agent that influenced by the unit data or service, and the changes would influence the individual agent's capabilities or responsibilities [6].

The Microservice architecture is a programming concept inspired by SOA. Instead of traditional monolith software application, Microservices provides groups of independent program components that operated, deployed separately yet based on precise protocols and dedicated memories. The Microservice architecture has gain popularity in the recent years; it has potential to contribute to the development of PIM concept. However, there is limited researches have been conducted and emphasised the topic [21]. Therefore, further validation through application use-case is necessary [22].

Service discovery or service discovery protocols (SDP) is an emerging field in the area of ubiquitous computing [23]. They provide a mechanism, which allows automatic detection of service offered by any node in the network. In other words, service discovery is the action of finding a service provider for a requested service [24]. Service discovery can potentially operate as a search engine for the PIM architecture [6].

3.4. System integration

Due to the complexity of the construction projects, the multidisciplinary stakeholders and implementation of heterogeneous data through the use of different software and hardware are hard to manage. Data integration becomes very critical, which enables smooth operation and effective collaboration [25]. A number of challenges regarding to data integration within the construction, were identified by FIATECH [26], which can be summarized as below:

- There is a lack of transferability, interoperability between data, systems, programs and methodologies,
- The comprehensive universal management tool for different phases of the construction project is yet not available,
- Lifecycle management issues are often not emphasised. Operation, maintenance, dismantle and recycling are taken less consideration,

• There is no common tool to manage health safety measures, and predictions of operation hazard are not available.

As a future construction IT system, PIM application will ensure construction information is available on demand and to be transferred to the desired stakeholders at the right time. All project partners, construction tools, equipment and machinery will be interconnected through integrated management systems. This will enhance planning, enable rapid response and optimize overall running of the project [27].

4. PIM concept development for external wall painting task

The Technical University of Munich (TUM) is commissioned by the Construction Industry Council Hong Kong (CIC) to research and develop construction robots and automation strategies that are tailor-made for the public housing construction project in Hong Kong. An extensive case study was conducted at Ngan Kwong Wan Road in Mui Wo, Hong Kong that erected by Hip Hing Engineering Co., Ltd. The project consists of one 14 stories and a 16 storey residential building. In this paper, the project team uses the 14 storey building as a case study to investigate how to implement PIM application to carry out external façade painting task by using a painting robot, which is developed during the CIC project.

First, the detailed breakdown of the working sequences and involved stakeholders and data for the exterior wall painting task are analysed. Whereas Figure 2 demonstrates the workflow for façade painting task carried out by a painting robot, Table 1 presents the corresponding data for each task description.

The main purpose of the proposed approach is to provide an automated process through accurate information flow from design phase to construction phase. Extension of the data stored in the BIM software is achieved by developing a property set. Pset_CIC_Painting is generated for schema IfcArchitectureDomain in the domain layer of the general IFC architecture. It has the properties of PaintingRobot, PaintingMaterial and MaxHeight. Data types for the criteria are set as IfcBoolean, IfcPropertyEnumeratedValue and IfcReal respectively. PaintingRobot finds out whether the façade painting is performed by a robot or not, MaxHeight refers to the maximum height of the external wall and PaintingMaterial includes the paint information.

CIC template file including the extended properties and building materials/composites for façade painting is created. The user should assign the each property using the IFC Manger menu. Pset_CIC_Painting is applicable to the project entity. Then, BIM file is exported as IFC format and transferred to an Excel file via IFC File Analyzer (IFA) [28]. In case of PaintingRobot being TRUE, the relevant data for the corresponding process can be extracted for the painting with automatic application.

Table 1. Robot-oriented painting task and related data.

Task description	Data bank
Installing the suspended working platform	Product, logistic, planning, bidding, labour, equipment, health & safety, repair & maintenance data
Delivering the painting robot and other accessories	Robot, logistic, planning, bidding, navigation, distribution data
Setting up & calibrating the painting robot	Robot, planning, equipment, repair & maintenance
Cleaning and preparing the external wall, skim coating of the wall	Robot, bidding, planning, equipment, repair & maintenance, labour
Applying the first coat of paint	Robot, paint supply, planning, equipment, repair & maintenance, labour
Conducting quality inspection	Robot, planning, equipment, authority
Applying the second coat of paint	Robot, paint supply, planning, equipment, repair & maintenance, labour
Conducting quality inspection	Robot, planning, equipment, authority
Applying the final coat of paint	Robot, paint supply, planning, equipment, repair & maintenance, labour
Conducting quality inspection	Robot, planning, equipment, authority
Finishing the areas where need to be painted again	Robot, paint, planning, equipment, repair & maintenance, labour
Dismantling the painting robot, hoisting device	Robot, planning, equipment, repair & maintenance
Dismantling the suspended working platform	Product, logistic, planning, labour, equipment, health & safety, repair & maintenance data

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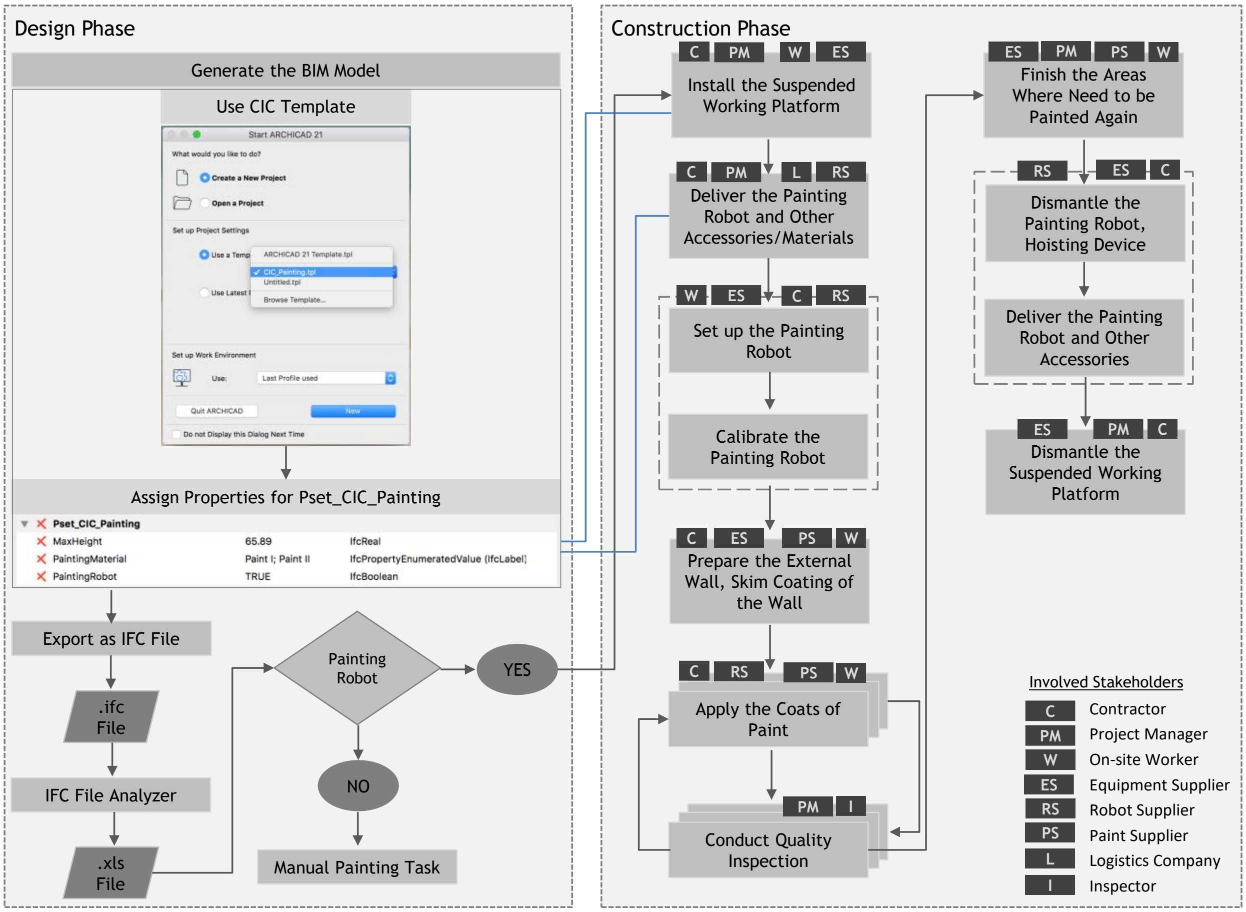

Fig. 2. PIM-based external wall painting task flowchart.

5. Conclusion

This paper provides an overview of the PIM concept and introduces a use case where how PIM applications would be operated while using the construction robotics on-site. The conventional BIM applications are designed to collect and distribute basic information about the construction project. However, they are not adequate in dealing with the situation if the construction robots are implemented. Since they have a limited function to understand the operational data generated by sensors and robots, there is a need of a more comprehensive approach. The concept of PIM enhances all aspects of the construction operations by not only collecting and distributing the data but also proceeding and analysing them for optimising the decision making during each task. The proposed approach provides systematic information flow and management for the construction phase of the project life cycle via incorporating the BIM data. This design and construction data integrated solution enables improved construction process management. In the current situation, BIM facilitates the design stage of a construction project and provides accurate project information, and continuation of the construction processes is separately handled based on the design data. Nevertheless, since most of the project delays and consequently cost overruns arise from the construction phase, more integrated and automated methodologies should be adopted. For instance, if the correct material/equipment information is gathered and transferred to the corresponding stakeholder as rapid as possible, the necessary actions can be made earlier than the actual construction to prevent any possible delays (e.g. in the façade painting case, checking the supplier of the paint automatically and in case of unavailability of that supplier, searching the possible ones via warning the related parties).

Moreover, the paper functions as an eye-opener to the construction industry through a demonstration on how to carry out BDE and BDA activities that associate with the vast amounts of heterogeneous data.

As mentioned earlier, at the time of this writing, it is limited to the conceptualisation of PIM. PIM is only developed as a conceptual idea that establishes the overall concept, yet will not bear on its ability of offering basic documentation tasks, provide instructions and data analysis by using existing Microsoft Excel tool. In addition, a comprehensive research project is needed to develop the concept further. It is important to use a real case study to develop the hardware and software environment, which required by PIM developers. Due to the given time and resources, the potential of the PIM application as a future Big Data application for the future construction industry, and privacy or data protection issues have not been detailed discussed.

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Rethinking the roles in the AEC industry to accommodate digital fabrication

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Abstract

As robots and other technologies take over tasks previously performed by construction workers and planners, the concern about the future of jobs and wages will increase. While digital fabrication (dfab), and particularly the use of robotic technology, has the potential to improve productivity, it should not necessarily reduce total employment in the construction sector in the long run. It is expected that existing roles will evolve, mainly related to the human-robot interaction, and new roles will be created (e.g., in addition to designers there would be a need for employees with digital skills). Particular attention should be made to the transition phase in which conflicts may occur between the old and new systems and planning methods. This will occur for different functions and services during the planning and execution of construction projects. Focusing on the construction phase of a concrete wall using additive dfab for the NEST building located in Dübendorf, Switzerland, the different roles were evaluated. From this study, it seems that robotic technologies and conventional construction will coexist next to each other for a while, leading to a higher job variability and the creation of new roles, such as dfab managers to support coordination required, dfab programmers to develop computer numerical control that can be implemented with industrial robots, or dfab technicians to support robotic systems. However, there is still a lot of uncertainty, making it difficult to quantify employment impacts. Therefore, further research is needed to evaluate the impacts of using dfab to the functional division, supply chain and business models of the AEC industry, and to assess additional social impacts, such as changes in education schemes.

Keywords: construction automation; digital fabrication (dfab); human-robot interaction; industrialized construction; integrated project delivery (IPD); project delivery and contract strategies, robotic construction; roles in the AEC industry

1. Introduction

Construction is distinguished from manufacturing in that the bulk of the production tasks typically occurs in a field setting and is undertaken in an uncontrolled environment [1]. Moreover, buildings are complex systems that cannot be conceived as serial products, such as an automobile for example [2]. Each building is designed and constructed according to specific conditions and stakeholder decisions, making automation harder to implement when compared to other industries (e.g., manufacturing). Automation involves machines, tools, devices, installations, and systems that are all platforms developed by humans to perform a given set of activities without human involvement. Although there are many definitions for automation, mostly depending on the sector in which it is used, there is no doubt that it is powerful. As Nof [3] said, automation "has a tremendous impact on civilization, on humanity, and it may carry risks." For this study, the concept of automation is directly related to the use of robotic systems or robots to assist construction workers or to perform construction tasks during onsite operations. In particular, this study deals with onsite robotic fabrication applied to additive construction, referred in this study as digital fabrication (dfab).

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Despite the fact that the construction industry is one of the oldest and represents a significant part of a country's GDP, it is also one of the most unfamiliar regarding the R&D fields for the automation community [4]. However, the research of robotic fabrication and robotic systems applied to construction operations is not new and has been around since the 80s. In 1984 Warszawski [5] published one of the first critiques about the use of robots in the building sector, trying to examine robot requirements, implementation and economic feasibility of their application. Exploratory studies were conducted in the fields of infrastructure ([6], [7], [8], [9]), digital design and production [10], surveying [11], prefabrication ([12], [13]) and assembly [14]. In addition, researchers started investigating the feasibility of robotic applications in various architecture and construction activities ([15], [16], [17]) and also for freeform construction ([18], [19]). Combination of construction automation with robotics has also been investigated ([20], [4]). However, early attempts in robotic construction did not succeed mostly because of the lack of computation power, and partly because of the highly specialized character of the robot developed and used [21].

Although the use of robotic systems, mainly those used onsite, is still very limited (a few examples include the Semi-Automated Mason [22] and the In situ Fabricator [23]), they are becoming technically and economically possible, and it is expected that they will gradually be used in the industry as cost-effective solutions are found. Another driving force pushing contractors to give a more serious look at robotics and automation is the shortage of construction workers. The aging working population coupled with the lack of new generation joining the construction workforce are giving construction companies a hard time finding qualified labor [24]. According to a survey by Autodesk and the Associated General Contractors of America (AGC), 70% percent of construction firms are having difficulties finding qualified craft workers to hire during growing construction demand [25]. This interest is not new. Something similar happened in the 1980s in Japan, where construction demand was booming. However, construction jobs were not attractive to young Japanese generations which triggered a substantial investment and research into construction robotics. After a significant amount of resources invested in the development of highly customized automation systems and robots, the technical excellence was never matched by economic success, causing the abandonment of the robotic pursuit in construction [26].

The study presented in this paper provides an outlook of the findings during the evaluation of an ongoing project in Switzerland in which robots are used for digital fabrication on site. Particular attention was given to the changing roles during the construction execution phase. Given the research and prototype nature of the case study, the observations from this study should only be considered as exploratory and not as a generalization for the construction industry. However, this type of studies can be useful to evaluate trends and changes in the roles of other projects and eventually forge new directions in the construction sector.

2. Current situation

2.1. Uncertain impacts on labor and workforce

As robots and other technologies take over tasks previously performed by construction workers, there will be a disruption in the current roles, from laborers to designers. This transformation in the construction sector will be accompanied by the concern about the future of jobs and an increase in wages. According to [27] 41% of construction jobs in Germany are at high risk of automation by 2030. 35% in the US, 26% in Japan and 24% in the UK. Studies for other industries have also investigated the effect of robots and automation to the social dimension. Frey and Osborne [28] estimated that around 47% of total US employment has a "high risk of computerization" by the 2030s, while the estimations by Arntz et al. [29] were quite a bit lower, only 10%. The findings in [27] are somewhere in between, estimating that 35% of US jobs are in danger of being lost to the robots. Recent debates about the future of jobs have mainly focused on whether or not they are at risk of automation ([27], [28], [29], [30]). Most studies have minimized the potential effects of automation on job creation, and have tended to ignore other relevant trends, including globalization, population aging, urbanization, and the rise of the green economy [31].

Although some studies and projections are pessimistic about the impacts to labor [28], others give a more optimistic view ([29], [32]), which is shared by the authors. The creation of new and specialized roles always happens when new technologies are introduced, and it is expected that the same will occur in the construction sector. While dfab will increase productivity ([33], [34]) it should not necessarily reduce total employment in the long run. On the contrary, robots and automation will create new jobs and provide new opportunities. It is expected that existing roles will evolve, especially during the transition phase (i.e., human-robot interaction), and new roles will be created. As indicated by [35], instead of drafters there would be a need for workers with more digital skills. This will occur for different functions and services, including planning and execution. The exact impact of the need of new roles, such as dfab Technicians to support robotic systems, dfab Programmers to develop computer numerical control that can be implemented with industrial robots, or dfab Managers and Coordinators, needs to be investigated in future research. One of the main advantages of using robotics in construction has to do with the potential to assist construction workers during the performance of repetitive or dangerous construction tasks in an autonomous manner, or with little supervision from laborers. This has the potential to make workers safer and reduce hazards, while also increasing productivity and benefitting the whole construction industry [36]. In addition, quality is expected to improve as robots would be able to deal with quality issues during production [37].

When comparing to traditional construction project phases, digital fabrication brings a significant change, particularly during the planning and construction phases. Digital fabrication introduces sophisticated human-robot collaboration based on robot sensory inputs. This builds a common base for exchange and collaboration among participants of different skillsets and machines. Many publications are about robots taking our jobs [38], or how machine learning, artificial intelligence, and automation, with the potential of outperforming humans, will eventually cause manual jobs to disappear ([39], [40]). The reality is far from those views, and current robotic systems and artificial intelligence are limited in their abilities to replace humans due to their inability to understand the complexity of our most basic real environment ([41]). Despite the unquestionable advancements in those areas, robots will not replace humans but will help them to make some tasks more efficient.

2.2. Traditional roles and responsibilities

The number of stakeholders in construction projects varies significantly, but in general, their number is considerable, and their interactions are complex [42]. The most basic parties can be grouped into the owner (or project sponsor), the designer/engineer, the contractor, financial/legal/marketing institutions, and the general public/user. These main parties have different important roles involved. For purposes of this study, we will focus on the designer/engineer and the contractor during the design and execution phases as indicated in Table 1. The different terminology used and key responsibilities are according to the service model from the Swiss Society of Engineers and Architects [43]. Slight variations regarding their name and responsibilities might be observed in different countries.

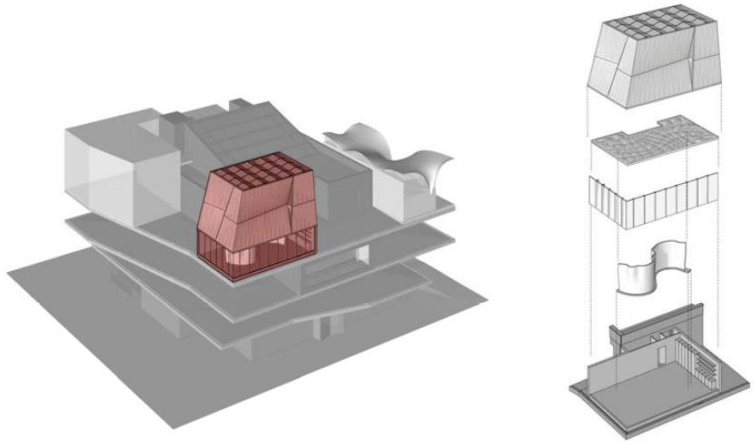
Table 1. Main roles and their key responsibilities

	Role	Main task
Planning/design	Leading designer/planner (project manager)	To coordinate the design/planning team
	Designer/engineer	To design a particular part of the project and often does the specialist site management for the part planned/designed
	CAD drafters	To prepare detailed technical plans or drawings
Construction	Construction manager	To coordinate the planning and execution of work on-site as a representative of the owner
	Site supervisor	To manage contractor’s team by assisting with the monitoring of onsite operations. Typically under the supervision of the construction manager
	Worker	To do the manual execution of the planned work, in most cases with the support of machines and tools

3. Case study

The investigation of the different processes and interaction among the project participants was done from February to July 2017 by graduate students doing their Master Theses at the department of Civil Engineering in ETH Zurich. They used the planning and execution of some elements from the NEST (Next Evolution in Sustainable Building Technologies) building, a research and innovation building being built at the Swiss Federal Laboratories for Materials Science and Technology (Empa by its German acronym) in Dübendorf, Switzerland. The observations made are only an excerpt of the ongoing processes of the NEST building. The NEST building is the backbone of several units aimed to test and advance technologies, materials, and systems under real conditions. One of those units is the DFAB HOUSE, a project lead by Empa in collaboration with the NCCR Digital Fabrication, ETH Zurich, and industrial partners. The unit consists of a three-story building (Figure 1).

Having several floors was done on purpose to show that dfab is possible for multi-story buildings. The DFAB HOUSE consists of four sub-projects, each carried out by a research team. The sub-projects are the Mesh Mould Wall, the Smart Slab, the Smart Dynamic Casting, and the Spatial Timber Assemblies. The different projects are summarized in Table 2.



(a) (b)

Fig. 1. (a) Empa's NEST building; (b) Different components of the DFAB HOUSE (source: NCCR Digital Fabrication, 2017).

The organization of the DFAB HOUSE project is rather complex since the two big entities EMPA and NCCR, as well as all other consultants and contractors, have to be integrated. The complicated organizational form is a direct consequence of the different research projects, involving many parties and decision makers. However, given the research nature of the project, there is a collaborative interaction among all the stakeholders not common in most public construction projects. The project delivery approach used was a combination between the Design-Build and Integrated Project Delivery System (IPD) [44], which allowed a superposition between the planning and execution phases as well as a fusion between the planner, designer, and contractor through collaborative interaction, particularly during the early phases of the project.

Table 2. Different projects for the DFAB HOUSE and general description

Project	General description
Mesh Mould Wall	To produce freeform loadbearing walls that can contain building services, with a steel mesh, assembled robotically on site with the In situ Fabricator
Smart Slab Team	To investigate the potential of additive manufacturing (3D printing) for the prefabrication of large-scale lightweight integrative building components
Smart Dynamic Casting Team	To automatically produce structures with variable geometry using the slip-forming technology
Spatial Timber Assemblies	To prefabricate a timber module robotically and assemble the elements on site

The project schedule was done using lean principles, in particular, the use of the Last Planner System. In addition, frequent meetings were also conducted among the different teams to ensure proper coordination. Although those meetings did not strictly follow the scrum concept [45], mostly because many of the artifacts were not considered, they followed a similar structure. As a coordination tool for the architect, the project manager, the designers and the research teams, several systems (e.g., Favro, Trimble) were used. The shared online platform was accepted and used by all participants since it was intuitive and familiar for most team members.

3.1. Evolution of existing roles and creation of new ones

The evaluation of the traditional roles observed during the planning and execution during the five months of interaction with the different participants at the DFAB HOUSE is summarized below. Only the roles related to the case study are addressed. There might be a number of additional roles which would be affected or would be created but are not considered in this study; therefore, the roles identified here should be used for illustration purposes only and not meant for generalization to the construction industry adopting automation and new technologies.

3.1.1. Planning phase

During the planning phase, most of the traditional roles are still applicable, but with some modifications regarding their primary tasks. For example, the project manager maintains most tasks as they are now, but as the projects become more automated or influenced by new technology, the coordination among the different project participants will be shifted towards new roles (e.g., dfab Manager). The role of engineers and designers during this phase will also remain very similar. Main changes were related to the implementation of the new working platform (e.g., using BIM) and using new software applications, such as the specialized plug-ins developed for the DFAB HOUSE. Similarly, CAD drafters would not change too much, only they will need to adapt to the new parametric software used to represent the different elements specified by the engineers/designers, their involvement would also be reduced as the automation of the project increases, but their need will not disappear completely. Also, new roles would be required. For example, dfab Managers, dfab Coordinators, or dfab Programmers.

The dfab Manager is a new role. This role arises once dfab becomes more preponderant in a project (similar to BIM managers in BIM-based projects). Some of the key tasks of the dfab Manager include:

- Writing and enforcing the dfab report (a report defining the scope of dfab) in cooperation with the project manager, the owner, and the involved designers.
- Defining the dfab goals.
- Defining the tasks, competencies, and liabilities concerning dfab for the different project participants.
- Defining the standards for the BIM models, model use, model exchange during planning, execution, and operation (at least the model handover to the owner).
- Defining the standards of dfab on the construction site. This includes soft- and hardware standards and interface and communication protocols used.

The dfab Manager is a highly experienced the field of dfab and knows the constraints of automated construction systems in general, and what are the elements to implement during the planning phase in order to have an efficient execution. She or he advises the owner regarding which level of automation might be optimal for the project. Since the whole set up of the project is done at the beginning of the project, the dfab Manager is also required then, or at the latest when the planner is hired. Once the set-up is done, the dfab Manager service for the project is done, and she or he might only be called for further strategic question arising during the planning process. The BIM manager could be brought into the project either as a client advisor or (specialist) consultant.

The role of the dfab Coordinator arises as soon as there is model coordination in a standardized way. Her or his level of expertise in the field of dfab is not as much as that of the dfab Manager. Since the planning of automated construction is suggested to be added to the BIM software, the main tasks of the dfab Coordinator include:

- Determining the coordination and methods required.
- Checking and validating of partial models (clash-detection), including the automated construction planning on site.
- Determining the necessary corrections, together with the project manager and the involved planners.

The dfab Coordinator is required in the project as soon as the BIM platform is set up. Her or his mandate would normally be included in the mandate for the project manager, meaning the planning office must have the necessary dfab knowledge and people. This is usually during the preliminary project or the construction project. Her or his role only ends once the models are delivered to the client during the close-out.

The role of the designer’s dfab Programmer is related to software design, which could be adapted from project to project. The main tasks would include coordination of the software (including fixing compatibility issues between participants and installation of plug-ins) and organization of the data storage and backup. The dfab Programmer is in charge of everything related to software, preparing it, so that the planners can work at their level of understanding of informatics. The dfab Programmer is mainly required in the planning process, as soon as the BIM platform is set-up, which is done in the preliminary project. It could be thinkable that the organization that is managing the project also brings in the programmer since their work is related. She or he stays available for the construction manager during the execution.

The utilization of these roles, or their participation share, changes depending on the amount of automation or technology (i.e., the level of digitalization) used in a project. A qualitative representation of this participation based on the level of digitalization is shown in Figure 2. Only the roles being discussed are considered (other roles might be applicable) and the variation shown is a qualitative assessment from the author’s observation of the case study. As depicted in Figure 2, the dfab Manager and the dfab Programmer only appear at an increased level of digitalization, since at low levels the tasks lay within the competences and knowledge of the current roles.

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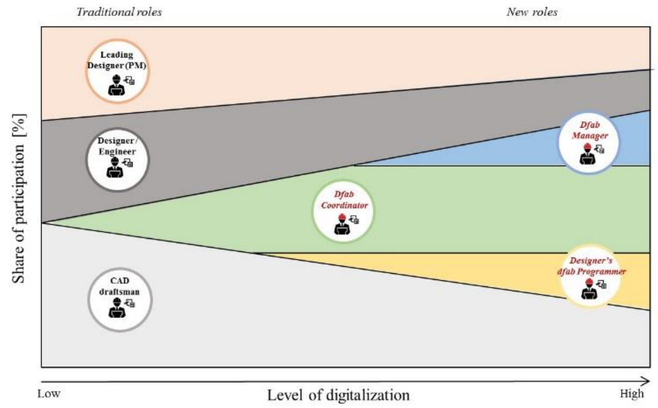

Fig. 2. Qualitative share of participation of each role vs. degree of digitalization during in the planning phase.

3.1.2. Execution phase

During the execution phase, most of the traditional roles are still applicable, but with some modifications regarding their main tasks or level of involvement. For example, the construction manager maintains most tasks as they are now; however, there is a shift of their workload due to the availability and reliability of information (e.g., fewer efforts to monitor and control schedule and cost, but more efforts to coordinate with programmers). Similar to the construction manager, the site supervisor's scope does not change a lot, but the workload shifts towards detail planning and monitoring of the robotic systems from a control room. With regards to the construction worker, her or his presence would be affected based on the amount of automation and digitalization used. One can think of this as an evolution from construction worker to dfab Technician. This would be an individual with experience in the execution of specific tasks, and that has been trained to operate or provide support to one or a few automated systems, similar to operators of heavy machinery (e.g., cranes, excavators) in current projects. Some of their tasks would include setting up the machine on site, supply the system with raw material. In essence, the dfab Technician does all standard tasks that are required to ensure a smooth development of the automated construction processes.

Another new role is the contractor's dfab Programmer. The scope defined for the designers' dfab Programmer during the planning phase is also applicable to her or him, but only internally to the contractor. However, for the internal task, there is a main difference: while the tasks of the designer's programmer are about creating the framework for planning, the tasks for the contractor's programmer consist of deducing the necessary codes for the robots from the BIM model. This also consists of the temporal planning (4D, in active interaction with the site supervisor and coherently to the timeline defined by the planners). The whole planning can then be checked by the dfab Coordinator, including the planning of all different contractors, showing the problematic points easily. The dfab Programmer is involved in the process as soon as the contractor is involved. Her or his work is then ongoing for detail-programming and adaption until the building is erected.

Similar to the planning phase, the participation share of the different roles would change depending on the level of digitalization of a project. A qualitative representation of their participation, based on the level of digitalization, is shown in Figure 3. Only the roles being discussed are considered (other roles might be applicable) and the variation shown is a qualitative assessment from the author's observation of the case study.

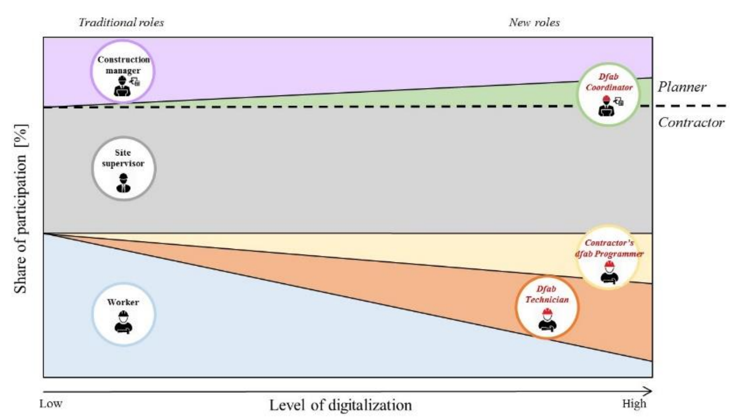

Fig. 3. Qualitative share of participation of each role vs. degree of digitalization during in the execution phase.

4. Conclusion and outlook

The creation of new and specialized roles always happens when new technologies are introduced, and it is expected that the same will occur in the construction sector. When comparing to traditional construction project phases, digital fabrication brings a significant change, particularly in the planning and execution phases. As a result, it is expected that current construction roles evolve, and new roles are created. There will always be tasks that will not be fully automated. The construction workers will not disappear, but their number will be reduced as the level of digitalization of a project increases. What is expected to occur is that the responsibilities of the construction workers will shift from unsafe and hard conditions to safer and less labor intensive, such as to monitor and control automated processes by transferring their know-how to the robotic systems. Although this study is not meant to be an exact representation of how the AEC roles will change, it opens the debate and research in this area, so that future studies can use this work as a guideline.

Further research is needed to evaluate the impacts of using dfab to the functional division, supply chain, and business models, as wells as the project delivery and contract strategies of the AEC industry, and to assess additional social impacts, such as changes in education and training schemes.

Acknowledgments

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Simulating the Workflow of Industrial Robotic Steel and Concrete 3D Printers to Build Organic Shaped Structures

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Abstract

For decades, humans have designed concrete structures according to limited shapes of concrete elements that can be cast into forms and rebar shapes that can be manufactured on a mass scale. Architectural creativity has always been bound by the structural design capabilities and constructability. With generative design emerging, organic shapes of architectural elements are expected to be more emphasized in design outputs. This is accompanied by organic design of structural elements and reinforcement shapes that are generated with optimized layouts based on algorithms that explore thousands of design possibilities. Manufacturing of such steel reinforcement has never been possible before. However, with the emergent of 3D printing and advanced robotics in steel printing, engineering designs are only bound by the architect's creativity. This paper aims to propose, analyze and optimize the workflow of concrete and steel printing robots on a construction project. Data on the printing properties (concrete and steel printing speed, robot speed, robot arm, etc.) are based on the best performing robots in the industry. Then agent based modelling using Anylogic was performed to simulate the printing of retaining and shear walls for a floor in a reinforced concrete building. Results show values used for later optimization of steel printing heads to concrete printing heads ratios using the current technology. Additionally, this study shows that the proposed method can reduce both time and cost in a construction project and provide cleaner, safer, more automated and unbounded construction processes. Findings from this research call for an in-depth investigation of the capabilities of steel 3D printing and its utilization in construction. It also highlights the importance of considering the application of new construction tools that would cope with the rapid growth of computational power, and its adoption in design practices.

Keywords: 3D Printing; concrete 3D Printing;, Steel 3D printing; Generative design; Robotics in AEC industry.

1. Introduction

Construction has always been lagging manufacturing, and this is true with the 3D printing industry as it is true for other industries. Globally, the 3D printing market increased from US$1.5 billion in year 2011 (Kilger & Wienken, 2016), to US$4.2 billion in year 2015 with only US$24.5 Million for the concrete printing industry (marketsandmarkets.com, 2016). An expected growth to US$22.4 billion in year 2020 (Alto, 2016) is expected with USD$56.4 Million for the concrete industry (marketsandmarkets.com, 2016). This increase is due to the wide usage of 3D printing in different sectors of the industry including aerospace, automotive, medical, architecture and engineering sectors. If considering only architecture and construction, this development was accompanied with the ability to 3D print various most importantly concrete (Khoshnevis, 2004), and steel (MX3D/Metal, 2015). Advancements in 3D printing means and materials allow architects to implement most complex designs using genetic algorithms (Larsen, 2012), and this will lead to a wider adoption of organic shapes for load bearing structural elements. If working with a steel structure, 3D steel printing solutions have been proposed and implemented (MX3D/Metal,

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2015). Concrete 3D printing of large scale complex geometries has also been studied and applied. Organic shaped concrete elements have already been generated using algorithms, and have been printed using ultra high strength concrete (Gosselin, et al., 2016), yet if looking at a real scale fully functional structural element, concrete should be reinforced with steel to better distribute internal forces that result from external effects. Fiber reinforcement has been used with concrete mortar to serve this issue, and while fibers enhance the mechanical properties of concrete, fiber reinforced concrete is only limited in use to a certain height since discontinuous reinforcement will not provide enough tensile strength for structural elements. In addition, using standard rebar would not solve the problem for two reasons: first the complex geometry of concrete would, in some cases, make it very difficult if not impossible to place standard rebar inside concrete and second the concrete 3d printing nozzle wouldn't be able to pass through the already erected vertical rebar. In this paper, a methodology for 3D printing organic shaped rebar and concrete will be proposed and its workflow will be simulated using Anylogic to determine its optimal configuration.

2. Concrete 3D printing

In 1997, Joseph Penga conducted an experiment on solid freeform construction where he attempted to 3D print cement by depositing a thin layer of sand followed by a layer of cement bonded by a blinder. Historically, this was the first attempt to 3D print cement (Penga, 1997).

Later, other methods of 3D printing were developed to serve the construction and architecture industry. Several researches considered the different methods of 3D printing for the construction industry such as (Khoshnevis, 2004), (Lim, et al., 2012), and (Gosselin, et al., 2016).

The main three additive manufacturing methods that suit construction and architecture are: Contour Crafting (Khoshnevis, 2004), D-Shape (Dini, 2008), and Concrete Printing (Lim, et al., 2009).

2.1 Contour Crafting

This method is based on extruding concrete from a nozzle and building forms layer by layer while smoothening layers using a trowel. The path that it takes is dependent on a CAD file that is linked to the robotic arm's program. It is characterized by its applicability in-situ, high speed, automation, and ability to use the robotic arms for other uses (Steel reinforcement, MEP fixtures, Lintels…) (Khoshnevis, 2004).

Despite its many benefits, this method has some drawbacks such as extra process requirements, weak bonding between batches due to segmented backfilling batches by a considerable amount of time interval (Lim, et al., 2012), and its restriction to print only 2.5D topologies (only in vertical direction) (Gosselin, et al., 2016).

2.2 D-Shape

D-Shape printing is a method developed by Enrico Dini. It is composed of a frame that has the print head mounted into it. These nozzles depose granular materials in layers and these granules are hardened by a binding material. When done printing, sand is removed from around the printed structure for reuse.

2.3 Concrete Printing

This method is like contour crafting where a cement is extruded through a nozzle layer by layer until the intended shape is built. However, this method allows for more geometric control due to the small nozzle size. Despite its precision, this method is slower than contour crafting and it only allows for off-site construction.

A recent study by (Gosselin, et al., 2016) aimed to explore a new way of printing concrete. In this study, an industrial 6-axis robotic arm was used to trace the printing path using the tangential continuity method (TCM) which in his opinion is better for large-scale additive manufacturing and would exploit the geometric potentiality of 3D printing technologies. TCM has also proven to yield more efficient and mechanically sound construction (Gosselin, et al., 2016).

This method is much like the fused deposition modeling (FDM), first the cement mortar is prepared and then conveyed using a pump to a mixing screw located in the printing head. Meanwhile, additives are added into the mix to accelerate the hardening of concrete right after it is extruded. This method could revolutionize construction and architecture since it could print complex 3D shapes with no addition cost and at large scale. The use of robots and the

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use of TCM method for slicing would automate the process, minimize waste and error, and would produce structurally sound concrete elements using high performance concrete. For all these reasons, the latter will be adopted in this study.

3. Steel 3D printing

Additive manufacturing (AM) has been around from 1987. Ten years after its initial emergence, ArmoMet developed laser additive manufacturing (Wohlers & Gornet, 2014), and so did this industry grow in a fast pace and is promising low cost of highly complex metal based parts (Ding et al. 2015).

On a high level of abstraction, AM process is classified to either a powder-feed/bed process, and as the name implied, powder is laid on a bed and the part is build layer by layer, or a wire-feed process where a wire is fed throughout a nozzle and melted using one of several ways discussed below.

Powder-feed/bed approach can print parts with high accuracy and functionally graded materials. However, its powder deposition is very slow compared to its counterpart, the wire-feed system. (Ding et al., 2015).

Wire-feed AM can also be classified into different processes depending on how the metal is disposed (Karunakaran et al. 2010). It has higher material usage efficiency and faster disposal rate that the powder-feed process which means waste is eliminated from the process and the risk due to using powder metals is eliminated (Taminger & Hafley, 2006). In addition, wires are less costly than powder.

Three main systems are found which are: laser based, arc-welding base and electron-beam based. Metal arc welding is most efficient is considering energy efficiency with an efficiency up to 90% compared to laser based with (2-5%) and electron beam with (15-20%) efficiency (Rännar et al., 2007). All wire-arc AM methods have a high deposition rate. Laser based AM needs a bed to dispose materials on and electron beam requires a high vacuum environment which is more suitable for aerospace applications.

Another innovative technology used by (MX3D/Metal, 2015) to print free standing 3D organic shapes using wire-arc AM and a robotic arm. This technology was used to create some fascinating projects such as the steel bridge in Amsterdam.

Arc-welding is the most suitable method available if is to be utilized in the construction industry due to its high disposition speed, low cost of equipment and materials, high efficiency and low volume which means ease of transportation or mounting on a robotic arm. For that we will be using the wire-arc process in this study.

4. Additive manufacturing missing chain in construction

The above literature review summarized the latest development in concrete and steel 3D printing technologies. Civil and construction management researchers have been trying to optimize and enhance the concrete printing process, yet they have not taken into consideration the compounding effects of the on growing complexity in architectural practices especially after the latest advancements in genetic algorithms (GA). The latter allows the computer to generate organic shapes which are much more optimized than any human design mimicking nature's evolution in this process, based on a set of algorithms and rules set by the designer (Swenson, 2016). Steel AM has facilitated the work of manufacturers and is starting to get architects interest as well, and the technology is quite advanced, yet it has not been implemented to construction yet. That is probably because of the low levels of innovation in the construction industry. Yet with the exploration of GA, new architectural shapes will emerge with a complexity not seen before. Here rises the need to explore alternative methods to design the structural aspect of those shapes. GA will have an important role in this design process since traditional rules found in building codes will not be sufficient to determine complex shapes integrity and robustness, neither will the available steel shapes help in shaping the steel that is generated with GA. This study aims to simulate the process of 3D printing a concrete member with organic shaped steel reinforcement and optimizing the number of steel 3D printing heads needed to maintain a balanced process.

5. Methodology

To reach the research objective, a stepwise research methodology has been designed. First the author conducted a review on the latest emerging technologies available in construction. This review led to studying and analyzing the deficiencies that 3D concrete printing still has from a structural engineer's point of view. Then, an innovative approach was suggested to solve the problem of reinforcing 3D printed concrete by incorporating steel printing into the process.

Due to the lack of technology that can implement this new approach, a simulation model is built to analyze the applicability of the process and assess its benefits and drawbacks.

In an earlier study, discrete event simulation was used to simulate the contour crafting process and its impact on construction was explored (Rouhana et al., 2014). For this study, agent based modeling (ABM) is used to simulate the process of concrete and steel printing. Parameter values that are used as input to the model have been collected from literature and from the latest technology available in the market. Two agents are defined which are the concrete printing robot and the steel printing robot. Simulation is done on the basement level of a concrete structure containing retaining walls on the circumference with a total length of 232.2 meters and shear walls in the middle with a total length of 36.375 meters. The story height is 4 meters. All wall thicknesses are assumed to be 20 centimeters. A 3D view of the structure to be studied is shown in figure 1.

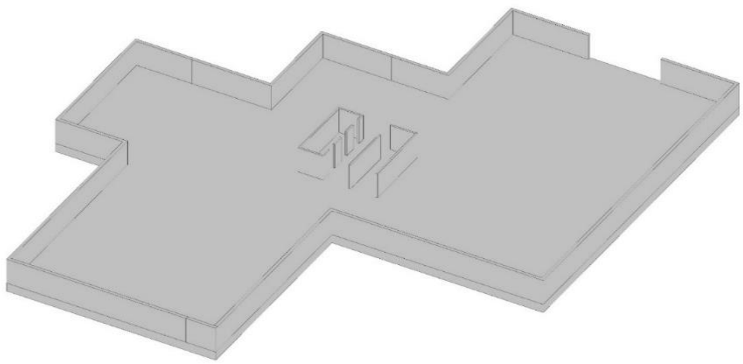

Fig. 1. 3D View of the printed walls

Steel reinforcement is assumed to be designed using generative design and optimization algorithms, hence the shape of steel reinforcement is not conventional (straight rebar can't be used). Also, no data is available on how much these algorithms will optimize our design. Alas, simulation of steel reinforcement installation is not possible. For that, steel 3D printing is used. Robotic arms enable freeform printing (moving is 6 axis) which satisfies our purposes of printing organic shaped steel. The ratio of reinforcement assumed in walls is the minimum reinforcement bound of 0.25% as per ACI 318-14.

6. Simulating the workflow of the 3D printing robots

Simulation of the workflow of both steel and concrete printing robots was done using Anylogic agent based modeling. State-charts, which describe the state of the agent and his corresponding activity, were constructed for both robots. All relationships within an agent and between the two interacting agents were defined.

For the Steel Printing Robot (figure 2 (a)), the state chart with the robot being Idle until it gets an order to start printing where it starts moving to the printing location. In its first round, steel does not need cleaning since no concrete has been poured yet, while in all other rounds steel needs cleaning from concrete so that wires are welded (printed) on a clean steel surface. Steel printing starts right after cleaning is done. The time for printing steel depends on several factors such as the area of steel inside the wall, the volume of the wall, the rate at which steel is printed and the length of the robotic arm.

When the robot finishes printing steel for a given segment, a message is sent to the concrete printing robot (figure 2 (b)) so that it would start printing in that segment. Meanwhile, the steel printing robot moves to print the next segment.

Concrete printing starts right after steel printing for a given segment is done and since the steel disposal rate is much less than the concrete disposal rate, the concrete printing robot will typically wait for the steel printing to finish. When the steel printing is done, the concrete printing starts, and when done the robot's state goes back to waiting for steel printing to finish.

The process is reiterated for each location that the robots will stop and print and when the robots finish one whole cycle for all the walls, a layer is finished and the count is added in the collections of "SteelLayerDone" and "ConcreteLayerDone". The process stops when the count in the collections reaches 40, which is the height of the wall divided by the thickness of each concrete disposal.

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The aim of this study is to optimize the number of steel printing heads, so the model was run several times and each time the number of steel printing heads was increased.

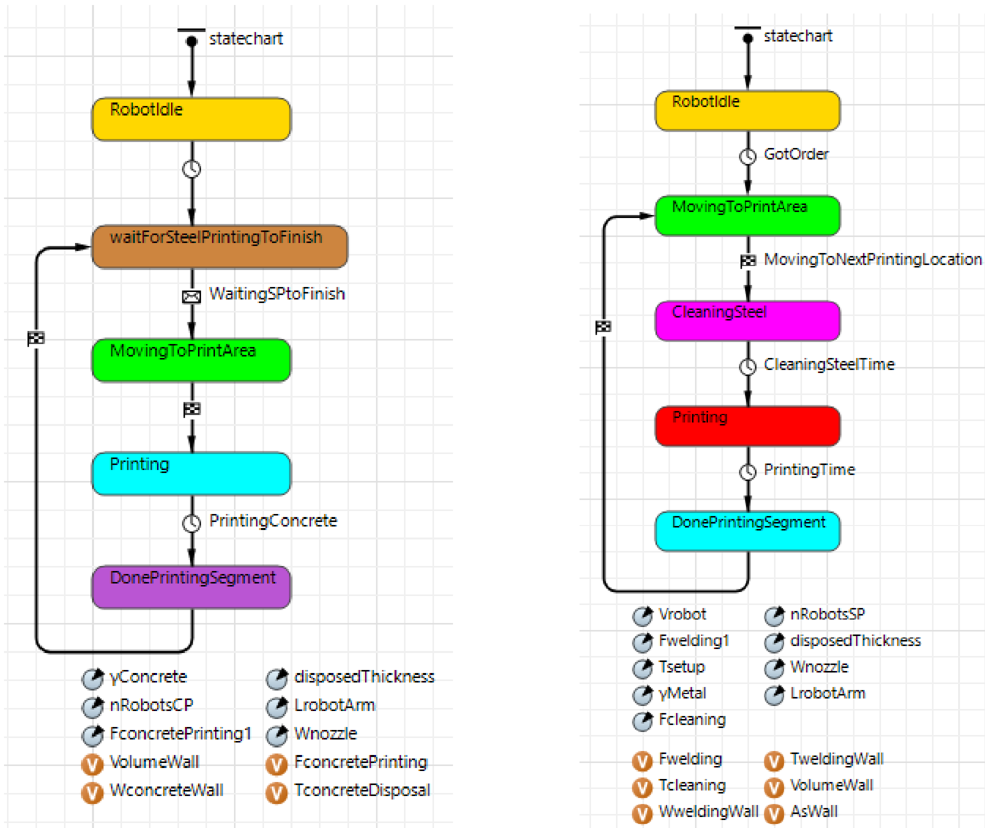

Fig. 2. (a) Statechart of the steel printing robot; (b) Statechart of the concrete printing robot

7. Model parameters and variables

Most parameters were collected from previous literature review and some parameters were assumed (such as number of steel printing robots). The parameters were then fed into the simulation model. Table 1 and table 2 below summarize all parameters assigned to both concrete and steel statecharts.

Table 1. Input parameters for the steel printing robot Statechart

Statechart: robotSP (Steel Printing Robot)		
Parameter in model	Parameter value	Parameter Definition
Vrobot	0.5 m/s	Speed of movement of an industrial robot
Fwelding	330 g/min	Rate of welding
Fcleaning	1.8 m/min	Rate of cleaning
nRobotsSP	Variable ranging from 1-10	Number of steel robots used
LrobotArm	2 m	Length of industrial robot arm
AsWall	0.0025*Wnozzle*disposedThickness	Area of steel inside the wall
VolumeWall	2*LrobotArm*AsWall	Volume to be printed per run
TweldingWall	WweldingWall/(nRobotsSP*Fwelding)	Time of welding
Tcleaning	LrobotArm/(nRobotsSP*Fcleaning)	Time of cleaning

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Table 2. Input parameters for the concrete printing robot Statechart

Statechart: robotCP (Concrete Printing Robot)		
Parameter in model	Parameter value	Parameter Definition
Vrobot	0.5 m/s	Speed of movement of an industrial robot
FconcretePrinting	12.7 cm/sec	Rate of concrete disposal
disposedThickness	0.1 m	Thickness of disposed concrete filament
Wnozzle	0.2 m	Width of the nozzle
LrobotArm	2 m	Length of industrial robot arm
nRobotsCP	1	Number of concrete printing robots
TconcreteDisposal	WconcreteWall / (FconcretePrinting*nRobotsCP)	Time for concrete disposal

8. Results and discussions

Results of the simulation models were summarized below. Figure 3 shows that when there was only one printing head of each steel and concrete printers, the total time of the operation was 11.5 days. The steel printer spent 9.08 days printing steel and 2.12 days cleaning printed steel from concrete. These numbers decreased when using ten steel printing heads to 0.8 days (19.2 hours) for steel printing and 0.19 days (4.56 hours) for steel cleaning with a noticeable change in slope at three printing heads where steel printing time is 2.95 days and cleaning time is 0.69 days (16.56 hours). As for the concrete printer, the time spent printing did not change as no variation was made in the number of concrete printing robots.

However, the time wasted while waiting for the steel printers to finished varied significantly from 10.19 days and a utilization of 9% when using one steel printing head to 0.3 days and a utilization of 77% when using 10 steel printing heads with a similar change in slope at 3 steel printing heads giving 2.66 days waiting time for concrete printing robots.

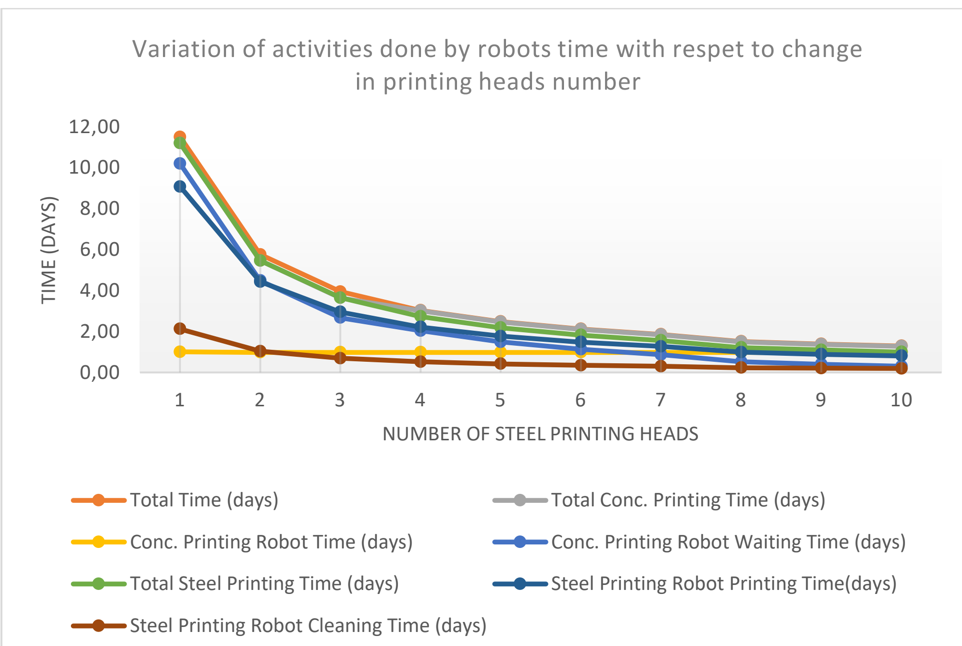

Fig. 3. Activity durations variation with the number of steel print heads used

Figure 4 shows that as the number of steel printing heads increases, the utilization of the concrete printing robot increases and the increase seems linear.

Ideally, it is best to choose the number of steel printing robots that would yield a minimum waiting time for concrete printing robot, yet each industrial robot is estimated to range between $150,000 and $220,000 (RobotWorx). However, Robot prices are declining. An online report published by "The Boston Consulting Group" shows that the price of industrial robots is decreasing and is expected to reach $103,000 in 2025. Despite the decrease in price, the performance of the robots is continually improving by an estimate of 5% per year (Sirkin et al., 2015).

A rough estimate of the time and labor cost needed to execute these walls was calculated and it was found out that the labor (4 carpenters and 2 helpers) would cost around $8500 and would take them from 8 to 10 days to complete this task. This project is a 7-story building so the total labor cost and time for execution of concrete walls would be $59,500 and 60 days respectively. This would be much cheaper than buying, for example 4 industrial robots (3 steel printing and 1 concrete printing) each at the cost of $133,000 and total cost of $532,000. However, this cost is only the capital cost and is not enduring. Figure 5 shows the variation of labor and robot initial and operation costs.

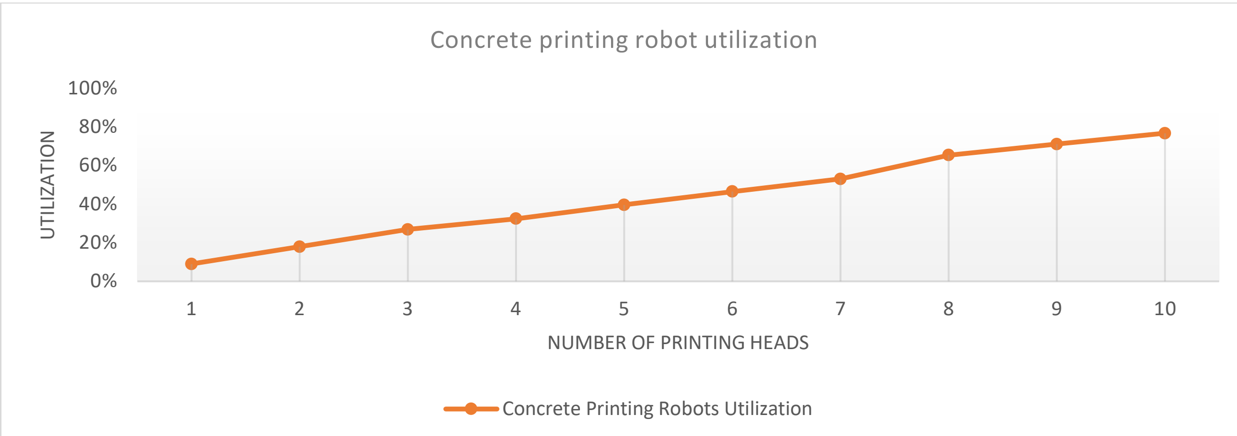

Fig. 4. Utilization of the concrete printing robot with variation of number of steel printing heads used

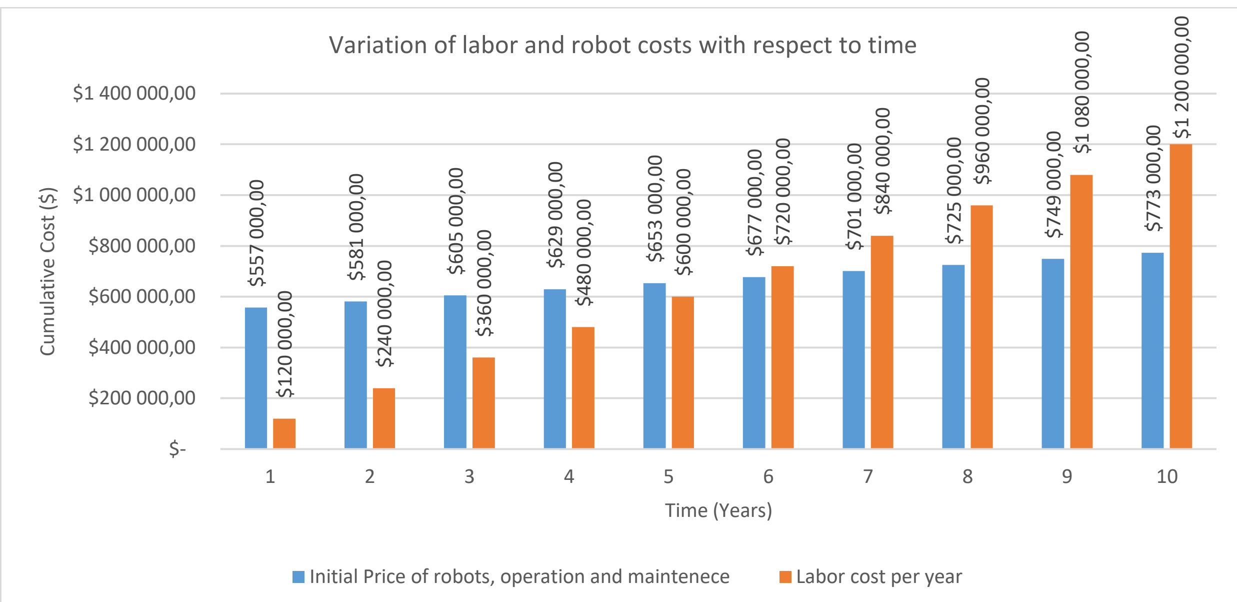

Fig. 5. Comparison between the variation of robot initial and operation cost with labor cost with respect to time

It is shown that after 6 year, the cumulative labor cost would be more than the cumulative cost of the robot initial and operational cost (if 3 steel and 1 concrete robots were used).

9. Conclusions and Future Work

In this study, the latest advancements in concrete and steel 3D printing were summarized. It was shown that concrete 3D printing is well utilized in the AEC industry, whereas steel 3D printing is mostly used in manufacturing and not utilized for AEC yet. The necessity for using steel and concrete 3D printing is arising in construction, not only to automate the construction process and reduce waste but to accommodate for the arising design complexities accompanied with the common use of generative design in architectural design and its possible adoption in structural design later. An agent based model was constructed to simulate the workflow of the steel and concrete printing robots and to generate data for later use in finding optimized configuration for the number of printers used. The results showed that there is a big gap between the capacity of concrete 3D printing and steel 3D printing. This calls for more detailed research on the utilization of steel 3D printing for the construction industry. In addition, further research is required in simulating 3D printing of different steel reinforcement diameters, varying thicknesses of walls and different column sections and correlating the time values of the proposed methodology with the fresh properties of 3D printed concrete mainly the open time which greatly affects the bond strength, which can compromise the structural integrity of the printed elements. Ongoing advancements in robotics, steel and concrete 3D printing will enhance the process studied and lead to wide adoption of robots and 3D printing in the AEC industry for a cleaner, safer, highly adaptable and more automated process.

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Smart Technologies in the future housing constructions

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Abstract

Researchers envision a future information society stemming from ubiquitous computing and intelligent environments. To a large extent, an ambient intelligent home called smart home no longer is science fiction and is technologically feasible. But reviewing the current state of the field shows that application of the smart home in real life and in the future housing constructions is still lacking; largely because the investigation of smart homes is limited to the domain of technical issues. But applying smart technologies in a home environment affects the way people live inside and outside of their home and shapes a new lifestyle. When the way of living changes the conditions of the dwelling change accordingly. However, usually the technology is added after the spatial design in the final design stage by the installation expert. Hence, a mismatch between the user demands and the smart home possibilities has been occurred.

In this paper, we turn this process around; the smart technologies are accommodated by spatial design and shape a smart home. Specifically, we model the new spatial characteristics of smart homes based on users` preferences. The model is based on the assumption that different individuals and households have different spatial preference of smart homes due to having various characteristics, lifestyles, and needs. A Bayesian Belief Network (BBN) is used for the modeling. It estimates the probabilities of choosing spatial characteristics of the smart home among different users with various sociodemographic characteristics. The spatial characteristics which are going to be predicted relate to the public-private layout of smart homes.

By determining new spatial organizations based on users` preferences, smart homes can practically provide spaces that respond to the users` needs in real life. Proper integration of technology with space and adjusted spatial conditions are vital for the accomplishment of smart homes and improving the users` acceptance.

Keywords: housing construction, smart technologies, technology-space integration, users` preferences;

1. Introduction

Applying new smart technologies in the current houses change many of the current living patterns of people. The lifestyle study of smart homes indicates that many of the daily living patterns are going to be changed by applying smart technologies in houses. But the home is meant primarily to support the activity “to live”. When living patterns change because of embedding the new technologies, conditions of the home need some redefinitions accordingly. In this paper, we aim to define optimal spatial layout of smart homes, that is, adapting interior spaces of a smart home to the users` needs and preferences in the real life and establishing the highest functionality of the applied smart technologies. But the main focus of this paper is given only to the public-private layout of smart homes.

Thanks to applying smart technologies in the domain of a home, the private zone of a smart home is going to be used less than an ordinary homes. People typically use bedrooms of the smart home only for sleeping. Instead, they prefer to do most of their daily activities, even working, in public areas and use the smart facilities. Thus, when activities

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move from the bedroom and take place in other spaces, bedrooms seem to be required less. There are some existing literatures, which claim that bedrooms in future houses will be replaced by cozy islands in the home layout. Certain rooms in the home will likely disappear and will be replaced by multifunctional spaces (Living Tomorrow lab [8], Horx [4]). Moreover, the main advantage of ambient intelligent technology in the smart home is improving the level of flexibility in the ways of doing activities. Any corner in the smart home is suitable for working or doing tele activities thanks to ICT and AmI technologies. Due to these changes, an architecturally distinct area is no longer required and the separation of work space and living space is increasingly broken down and rearranged by "blurring boundaries" (Leonard et al. [7]). In such a scenario, some granted boundaries between spaces may dissolve. The former physical separation of work or personal activities in the private spaces and other daily activities in the public spaces of the home does no longer apply in the same way. The home allows users to experience open and livable flow in the multifunctional smart zones rather than separate rooms. Hence, public- private layout of a smart home needs some redefinitions regarding to the proportion, the integration and the level of flexibility between the public and private zone. For defining the optimal spatial layout of the public-private zone, we conduct an experimental research. In fact, we investigate the new layout based on users` preferences. In the following, the method for eliciting users` preferences and accordingly estimating the optimal spatial layout are discussed.

1. The experiment

1.1. Implementation of the experiment

Smart homes are not still widely being applied in the housing industry and are mostly applied in a living lab environment. Implanting an experimental research on smart homes could be challenging in this regard, since the majority of the respondents does not have enough comprehension of the subject. In the implementation of the experiment, we take this issue into consideration. We design the experiment in a way that respondents not only explore how a smart home will look like, but also can interact with it. In fact, we first improve the experience of respondents from the smart homes and then elicit their preferences through some tasks instead of asking some direct questions. Through the tasks, users can rearrange spatial layout of a smart home. In fact, to have a more trustworthy experimental approach, we are going to explore how people make a smart home. Through their design choices, we elicit the spatial preferences of different target groups.

1.2. Design of the experiment

We use our developed prototype application as a platform for applying the experiment (Heidari *et al.* [3]). The virtual smart home presented in this prototype consists of several smart technologies, namely, smart walls, smart kitchen table, smart private zone, and smart furniture. We design the experiment with three steps, which are executed in the virtual smart home by users in the real-world: Step 1) the initial questionnaire, Step 2) a virtual tour through the smart home, Step 3) spatial arrangement. These three steps are depicted in Figure 1.

The experiment starts with an initial questionnaire with multiple sections, in which we ask some questions about the respondents` characteristics (step1). Then, respondents take a virtual tour though the smart home environment and watch several movies about smart technologies in a smart home (step2). In this part, we introduce a smart home to the respondents, let them explore the spaces and the embedded smart technologies in it, and accordingly improve their experience of the smart homes.

Step 3 is the spatial arrangement, in which respondents make multiple design choices for different parts of a smart home and design their preferred home layout. For each part, respondents explore multiple design alternatives and then choose one of them. In fact, a respondent can explore all the possible combinations until reaching to the final decision and selecting the most preferred layout. The spatial preferences can be elicited from the selected layout. While the design alternatives cover different parts of a smart homes, we discuss only the public-private layout in this paper. The possible combinations for the public-private layout are: a) small, integrated private, no flexible room, b) small, integrated private, flexible room, c) medium, semi-separate private, no flexible room, d) medium, semi-separate private, flexible room, e) large, separate private, no flexible room. All the alternatives related to the public-private layout are depicted in Figure 2. As depicted, the alternative (e) which has the largest bedroom cannot offer the extra flexible space. Since having a flexible space requires spatial reduction of the private zone. This alternative defines a large private zone with equal proportion among private and public zone, fixed boundaries and no opportunity for having flexibility. Hence, it is the most similar layout to the current houses.

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Open plan layout	Flexible/integrated layout	Separated	Separated/flexible	Separated
Smallest private zone No flexible room Largest public zone	Smallest/flexible private zone flexible room Largest/flexible public zone	Middle private zone No flexible room Large public zone	Middle private zone flexible room Small/flexible public zone	Largest private zone No flexible room Smallest public zone

Fig 1. An illustration of the choice alternatives for the public-private layout

1.3. Conducting the experiment

The experiment was Internet-based with the sample size of 250 respondents. From all of the respondents, 48.8 percent were single incomes, 41.7 percent were dual incomes, while the remainder were not working. 76 percent of the respondents were less than 34 years old (young), 20.5 percent were between 35 to 54 years old (middle aged) and the remainder were above 55 (elderly). This sample contains international respondents mainly from Iran, the Netherlands and other countries.

2. Model Specification

In the this paper, we aim to define the optimal public-private layout of smart homes, which is adapting the spatial aspects of these zones to the users` needs and preferences in the real life and establishing the highest functionality of the applied smart technologies.

Hence, a Bayesian Belief Network (BBN) is used to estimate and formulate the relations between the variables that directly and indirectly influence on the users` spatial preferences of smart homes. A BBN is composed of a set of variables, connected by links to indicate dependencies. It also contains information about relationships between the variables. For each variable, a conditional probability table (CPT) is provided, which quantifies how much a variable depends on its parents (if any). The belief network can be used for measuring users` spatial preferences since we can use the cause-effect relations between nodes to represent causal relations in the preference structure. Orzechowski [10] has proven in the past, that a learning based approach like the Bayesian Belief Networks allows estimate users` preferences in a choice model. Using the Bayes rule, the posterior belief p (A|B) can be calculated by multiplying the prior belief p (A) by the likelihood p (B|A) that B will occur if A is true.

$$P(A/B) = \frac{P(B/A).\ P(A)}{P(B)} \quad (1)$$

The Bayes' rule is helpful in many situations where we want to compute p (A|B) but we cannot do so directly (Orzechowski [10]). It is common to think of Bayes' rule in terms of updating the belief about a hypothesis A in the light of new evidence B. In the following, we argue how we apply this method to predict spatial preferences (as hypothesis A) in the light of new evidences of the users` characteristics (e.g. working status and age) and other external influencing factors such as size of the smart home.

The estimation of a BBN requires, as a first step, the process of learning the network structure of the data, and then estimation of the conditional probability tables (CPT) (Cheng *et al.* [2]). The constructed BBN (Figure 2) is compiled and displayed in the Netica (Norsys Software Corp [9]).

It is going to estimate optimal spatial layouts for the public-private zones of the smart homes. The presented BBN in Figure 2 is part of a huge network with multiple nodes indicating more spatial aspects (e.g. Smart living room layout or smart kitchen layout) and more influencing factors on users' preferences (e.g. Users` characteristics and lifestyles). In this paper, a particular emphasize has been placed only on the most important influencing factors on the preference for the public-private layout.

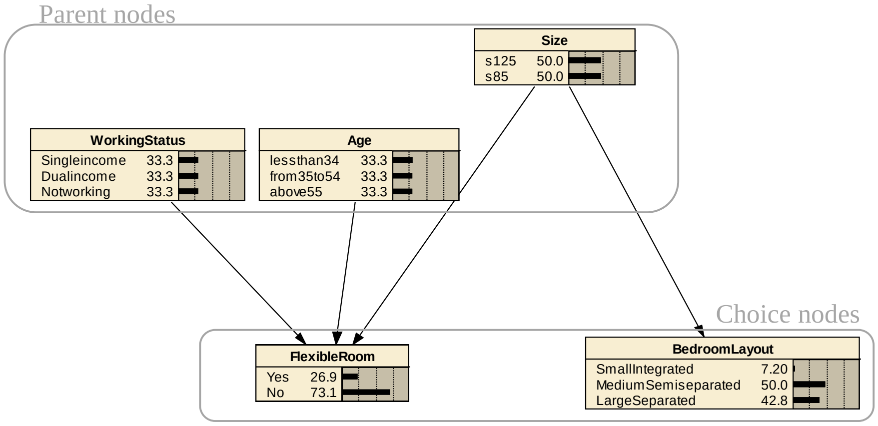

Fig 2. The constructed BBN estimating users` preferences of the public-private layout of a smart home based on their characteristics and the size of the smart home

3. Results

3.1. Spatial preferences in different sizes of smart homes

It is assumed that the size of smart home has an important effect on users` preferences. While smart technologies can easily be added to a large sized house without any cost concerns, applying smart technologies in smaller sized houses should be based on economic feasibility. Due to the matter of cost, there will be a low chance for smart homes to be accepted by middle or low incomes, especially if the applied smart technologies cannot really improve the quality of space. Hence, spatial design of smart homes with a limited size would be so challenging if smart homes want to be targeted for a wide range of target groups. In this study, we focus on the two sizes of 125 m^2 and 85 m^2 to evaluate the effects of limiting the size on the users` spatial preferences. 125 m^2 is considered as a normal sized smart home and 85 m^2 is considered as a small scaled smart home.

Table.1 probability estimation of the BBN for users` preferences of the public-private layout in different sizes

	Size125	Size85
Bedroom Layout		
Small/Integrated	**11.378**	3.0173
Medium/Semi-separated	40.97	**59.047**
Large/Separated	**47.652**	37.936
Flexible Room		
Yes	20.342	**33.555**
No	**79.658**	66.445

As represented in Table 1, the preference for the flexible room goes down and the preference for the large, separated bedroom layout goes up in a 125m^2 smart home; because, there is enough space in this size to apply smart technologies only in the public zone, while keeping the private zone as large and separated as it is (Figure 2, combination e). But according to the estimations in Table1, despite of such a kind of high preference for the large, separate private zone in this size, the majority of people prefer to minimize and integrate the private zone of the smart home; the total probability of choosing the small, integrated bedroom layout and the medium, semi-separated layout (52.348 %) is higher than the probability of choosing the large, separated bedroom layout. More specifically, the preference for the small, integrated bedroom layout (Figure 2, combination a) significantly increases in this size in comparison with the 85 m^2 smart home. To conclude, although there is a risk for users to fallow the multi room layout of thier current houses in a 125 m^2 smart home and do not modify the private zone, the hypothesis of minimizing the private zones and prefering a more open plan layout is valid in this size. In contrast, by decreasing the size of the smart home into the 85 m^2, the preference for the medium, semi-separate bedroom layout with the extra flexible room increases (Figure 2, combination d). This result is an indication that having a large living room by minimizing the bedrooms and making them flexible is the priority in people`s design decision for a small scaled smart home. In this size, applying smart technologies, mainly affects the private zone of the Smart home. The majority of people prefers to reduce the size of the private zone and accordingly have a larger living room. The increasing preference for the flexible room is due to the reason that the flexible room can be completely open to the living room whenever it is not needed and therefore it can create a larger living room. To conclude, applying Smart technologies in small scaled houses can really open up inessential separations and makes more open space and flexible layout for these houses.

3.2. Spatial preferences based on users` working status and age

According to the BBN, the working status and the age of people influence on their preferences for the level of flexibility between the public zone and the private zone in smart homes. Figure3 shows how these two nodes change the probabilities of choosing the flexible room.

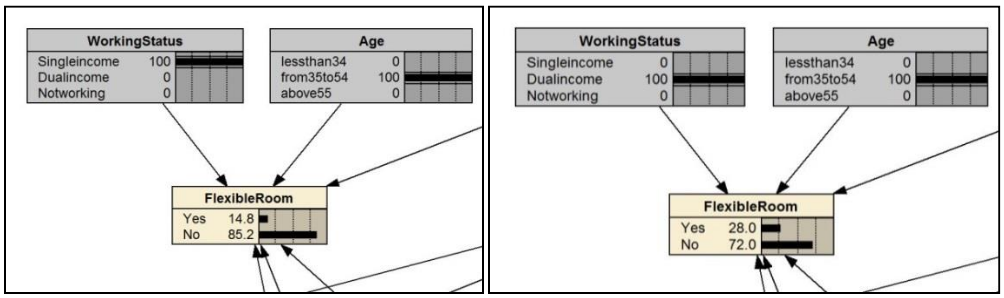

Fig.3 A screen shot of the BBN showing the flexible room node with its parent nodes of working status and age

In this part, more detailed exploration is given about the variation of this general preference among people with different age and working status. According to Table 2, the preference for having the flexible room is increased by increasing the age. While young people in all of the working status have the least preference for the flexible room, elderlies have the highest preferences for it. The reason may rely on the fact that elderlies need to manage their privacy more than other people and the flexible room can help them in this regard. People, who not-work (retired, housewives and etc.), have an increasing preference for the flexible room. They usually spend a lot of time at home. Hence, flexibility of spaces is more important for them compared to people, who work out of the home. Moreover, dual incomes have a higher preference for the flexible room than single incomes. Dual incomes usually have a busier lifestyle than single incomes. They usually have a tight schedule while they are at home. Hence the flexible room can help them to reduce the possible conflicts among their activities. In conclusion, while the general estimations indicated that the flexible room is not largely preferred in smart homes, case analysis on the BBN reveal that elderlies, not-working people, and dual incomes are the potential target groups for the spatial flexibility inside the smart homes. They are people, who need different ranges of privacy and a flexible room helps them to adjust the privacy of spaces according to their different types of activities.

Table.2 Updated probabilities of the preferences for spatial layout of the smart home based on the working status and age (%)

	Single inc, young	Single inc, middle aged	Single inc, elderly
Flexible Room			
Yes	10.296	14.8	**26.231**
No	89.704	85.2	73.769
	Dual incomes, young	Dual inc, middle aged	Dual inc, elderly
Flexible Room			
Yes	20.735	27.961	**43.526**
No	79.265	72.039	56.474
	Not-working, young	Not-working, middle aged	Not-working, elderly
Flexible Room			
Yes	22.63	30.21	**46.147**
No	77.37	69.79	53.853

4. Conclusion

The most common concept of space in current houses is its categorization by functions, such as sleeping rooms, working room and living room (Junestrand [6]) that can be traced to the "form follows function" design philosophy by American architect Louis Sullivan`s established more than a century ago. But the gained results in this paper revealed that smart technologies have the possibility to break down many of the boundaries, separations, and spatial limitations in the internal spaces of houses. Applying smart technologies decreases the occupied area and the separation of the private zone at homes. The private zone becomes more flexible in smart homes. Hence, the public zone becomes larger and more integrated to the private zone. Such a kind of change from the multi-roomed layout to a more flexible, multifunctional open plan layout in smart homes matches better with the new living patterns of an information society. However, these spatial modifications are mainly applicable for target groups, who really can be benefited from the smart technologies. Only if people really utilize the smart technologies in their daily life, they try to modify the space in order to achieve the full functionality of the smart technologies. For this reason, dual incomes more than single incomes, elderlies, and middle aged people more than young people, inhabitants of small scaled houses more than people, who live in larger houses, prefer a flexible and open layout in the smart homes. In conclusion, by increasing the age and numbers of people who work at home or by decreasing the size the need for applying the smart technologies is increased and accordingly the preference for having more flexibility and integration in the public and private zone of a smart home is increased. But if people do not really need the smart technologies and do not apply them in their daily life, there is a high probability that they prefer the most similar layout to the layout of their current house; because people generally get inspired from the spatial layout of their current house.

To conclude, eliciting spatial preference of different target groups and apply them in the smart home design broaden the domain of smart homes from a technology-driven industry to the future housing industry and real estate. There is a great opportunity to apply the smart technologies not only in living labs, luxurious houses, or assisted houses, but also in more common types of housing, like the small and medium sized apartments.

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Volume - forming 3D concrete printing using a variable - diameter square nozzle

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Abstract

3D Concrete Printing (3DCP) process is rapidly developing worldwide, showing its ability to construct large-scale components or even a building. However, the current 3DCP process has found it hard to manufacture architectural components with detailed ornamentations and features on their surface due to the Fused Deposition Modelling (FDM) manner that generates fixed-width thick filaments. This paper introduces a novel Volume - Forming 3D Concrete Printing (VF3DCP) method applying a variable-diameter square nozzle to manufacture architectural ornaments. The VF3DCP method directly fabricates a variable cross-section volume during one-time work instead of an FDM accumulation process. A VF3DCP extrusion kit prototype containing a steering module and a nozzle-varying module and a particular adaptive tool path planning algorithm are developed. Functional relationships of four key process parameters for a trial material, including nozzle diameter, nozzle moving velocity, material extrusion rate and tool path curvature radius, are fitted by process tests. Finally, a case study into a VF3DCP architectural carve pattern is conducted, which shows the potential of the proposed method in manufacturing architectural ornaments.

Keywords: concrete printing; volume forming; variable nozzle; architectural ornament

1. Introduction

3D Concrete Printing (3DCP) processes have been gaining ground since the first process was developed, notably in the mid-1990s in California, USA, when Khoshnevis released a method termed Counter Crafting (CC) [1]. This process was continuous extrusion - deposition of concrete filaments to manufacture a wall structure. Another notable work was published by the team at Loughborough University [2,3], who used a similar process to fabricate large-scale components (i.e. wonder bench, doubly-curved panel). Now there are more than 35 institutes and enterprises participating in this developing area [4-10]. As the most prevalent Additive Construction (AC) method [11], these 3DCP processes are supposed to provide the construction industry with enormous potential benefits (i.e. labor, cost, waste). According to Bos et al. [12], the current 3DCP groups are either production-oriented or performance-oriented; nevertheless, both of them are drawing the public sight into the ability of the 3DCP process to construct large-scale components (e.g. walls, columns) or even buildings (e.g. houses, offices).

Compared to powder-based AC method [13], the 3DCP process that adopts the Fused Deposition Modelling (FDM) principle, usually has lower printing resolution on printed surfaces. This can be termed as a Line - Forming method, that is, the nozzle of a printer deposits material in lines (filaments) and numbers of lines accumulate to obtain a surface and then an entity. Usually, a predefined nozzle diameter is used for an entire Line - Forming process, which inevitably causes the staircase effect - a geometric approximation manner of a curved surface by uniform-thickness layers [14-

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16]. Acceptable geometries may be achieved by such 3DCP process for constructing large-scale components if the fixed-width filaments are thin enough. Referring to Loughborough's achievement of 6mm for filament width [17], the limit on the minimal filament width has severely inhibited the 3DCP process from manufacturing architectural ornamental components which typically possess fine and intricate features (e.g. patterns, carvings) on their surface (Fig. 1). When implemented with fixed-width filaments, the 3DCP products are likely to have missing and superfluous parts, or even distortions, which is an inherent deficiency of 3DCP process.

Fig. 1. Façade panel, carved window and decorated bracket with patterns.

To fabricate accurate geometries of architectural ornaments as well as other grotesque functional components, this study attempts to revolutionize the current Line - Forming 3DCP process by a novel Volume - Forming 3D Concrete Printing (VF3DCP) method using a variable - diameter square nozzle. The VF3DCP process aims to provide a conventionally fixed-width filament with distinctly variable cross-sections, transforming the filament from a line into a volume. The VF3DCP method is able to directly fabricate an entity formed by variable cross-section concrete filaments (or lumps) during one-time work instead of line accumulation, which is rather different from the Line - Forming process. This is supposed to produce excellent geometries for components with high-quality outward appearances such as architectural ornaments. A custom VF3DCP extrusion kit prototype is designed to demonstrate the process and a case study of a carve pattern manufacture is undertaken to validate the VF3DCP method.

2. VF3DCP extrusion kit prototype composition and running mode

The patented VF3DCP extrusion kit prototype (Fig. 2) is mounted on a steel lifting beam of a movable gantry. The kit consists of four functional modules, referring to mixing module, depositing module, steering module and nozzle - varying module. The nozzle is designed into a square and the modularized design of the kit makes it easy to disassemble and assembled each module.

- *Mixing module*: this module mainly includes an electric motor, a stirring impeller and a charging spout. The electric motor powers the stirring impeller with an appropriate rotation rate to keep the mobility of the cement mortar fed into the charging spout.

- *Depositing module*: this module mainly contains a servo motor with a reducer, a coupling, a bearing block and a screw conveyer. Driven by the reduced servo motor, the screw conveyer sucks the stirred material in the charging spout and vertically deposits it in a required flow rate.

- *Steering module*: this module mainly incorporates a servo motor with a reducer, a turn-barrel and a locking block. The turn-barrel, besieging the screw conveyer through the locking block, is driven by the servo motor to rotate the square nozzle according to tool paths.

- *Nozzle - varying module*: this module mainly comprises a servo motor with a reducer, a rotary turntable, a spacing plate, four small isosceles - triangle plates with four pairs of sliders and tracks. Powered by the motor, the rotary turntable rotates to make the plates centrifugally or centripetally move to change the nozzle diameter.

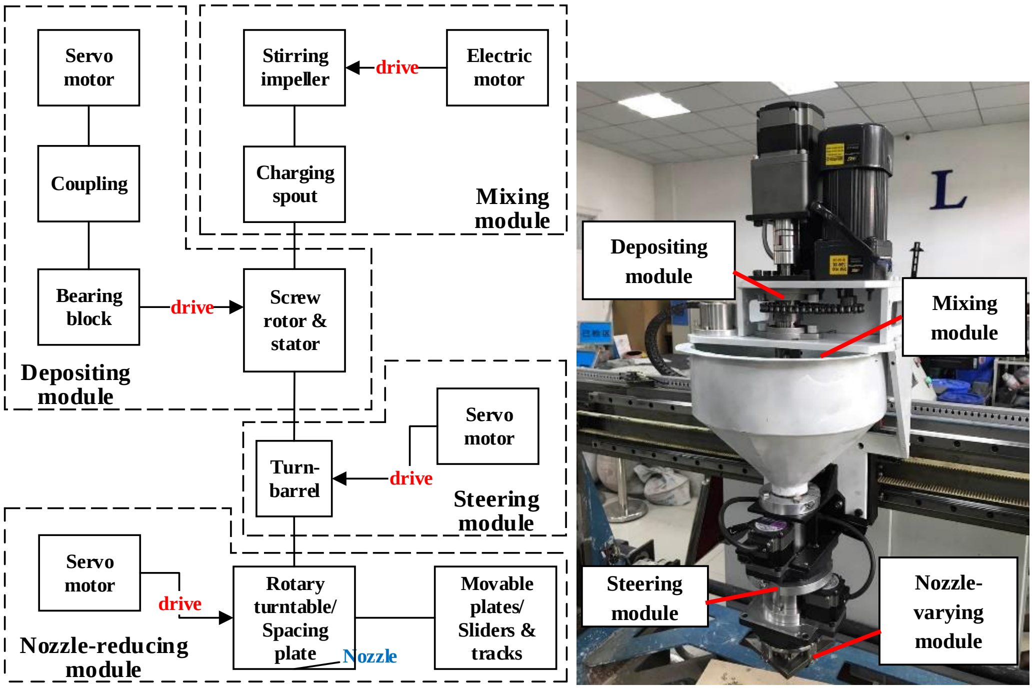

Fig. 2. The VF3DCP extrusion kit prototype composition.

A Volume - Forming process means that the width, height and orientation of any cross-section of a filament should precisely equal to the target geometry, which primarily results from the co-operative running of the nozzle - varying module and the steering module. The four identical isosceles - triangle moveable plates of the nozzle - varying module closely join up with each other in the same horizontal plane, generating a centrosymmetric structure. Every plate gains a rigid connection with a slider that links with a turntable via a bearing. When a rotating signal is received, the servo motor will drive the turntable to rotate relatively to the turn-barrel of the steering module, causing the four sliders to simultaneously slither along their tracks upon a board fixed on the turn-barrel. Then, the four isosceles - triangle plates are forced to move centrifugally or centripetally, which brings about displacements along interfaces of these plates to obtain a variable - diameter square nozzle. Notably, the square nozzle is able to change its diameter from 0mm to 25mm while its center keeps constant (Fig. 3). The steering module is in charge of driving the moving nozzle to rotate. When a rotation signal is received, the turn-barrel will be rotating synchronously with the revolving part of a servo motor, which finally causes the nozzle rotation. This ensures two opposite edges of the square nozzle to be constantly parallel to tool paths, achieving excellent surface perpendicularity of deposited filaments. Therefore, the coordinated running of both the nozzle - varying module and the steering module makes it possible for the extrusion kit to manufacture a complex geometry volume.

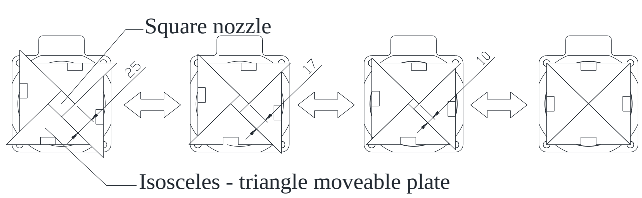

Fig. 3. The variable - diameter square nozzle for the VF3DCP process.

3. Process tests for functional relationships fitting of key process parameters

To realize a VF3DCP process, functional relationships of process parameters need to be set up to run the machine with a particular material. Generally, the key process parameters include the nozzle diameter, the nozzle moving velocity, the material extrusion rate and the tool path curvature radius. However, these parameters can critically vary from different material composition applied for manufacture. To demonstrate the VF3DCP process, a feasible material composition is proposed (Table 1). The P.C32.5R Composite Portland cement is used while the natural river sand is screened at 1.2 mm. A 30s dry mixing of cellulose ether, cement and sand is taken, followed by another 3min wet mixing. With this trial material, functional relationships of the key process parameters are respectively fitted by experimental matched values of these parameters from two process tests (room temperature) on the stipulation that both width and height of any cross-section of a filament always equal to the nozzle diameter. Test I is to determine the functional relationship among the nozzle diameter, the nozzle moving velocity and the material extrusion rate; test II is for the functional relationship between the tool path curvature radius and the nozzle moving velocity.

Table 1. Trial material composition.

Item	Water-cement ratio	Sand-cement ratio	Water reducer addition amount (relative to cement)	Cellulose ether addition amount (relative to cement)
Value	0.35	1:1	0.1%	0.05%

3.1. Process test I

In this test, four nozzle diameters of 10mm, 15mm, 20mm and 24mm (25mm is discarded for that the nozzle would easily get stuck) are respectively used to deposit four groups of straight filaments in length of approx. 20cm. Each group has ten filaments with different nozzle moving velocities varying from 10mm/s to 100mm/s (gradient value of 10mm/s) and different suitable material extrusion rates. By naked - eye observation with ruler measurements on three interquartile positions of a filament, each filament has to be checked on the geometry conformity between its cross-section and the nozzle. Usually, a number of different extrusion rates are tried to fit in with a certain nozzle moving velocity for a set nozzle diameter before a suitable extrusion rate is recorded manually. The satisfactory filaments are presented in Fig. 4 with gradually increased nozzle moving velocities from the top to the bottom for each group. However, there can be measurement errors of 1-2mm deviations for the filament cross-sections. The first five and the next five filaments in the group of 10mm nozzle are deposited in two different places (Fig. 4a). The material gets a bit drier after an open time of approx.90min when filaments of 20mm nozzle diameter are deposited, resulting in some surface cracks and the last filament of 100mm/s nozzle moving velocity is left out due to a material shortage (Fig. 4c). The last group of filaments is deposited using newly mixed material (Fig. 4d). Notably, filaments of the second group, the 15mm nozzle diameter, have the most excellent printed surfaces.

a b c d

Fig. 4. Four groups of deposited filaments in different set nozzle diameter, (a) 10mm; (b) 15mm; (c) 20mm; (d) 24mm.

The experimental matched values of the three process parameters are recorded in Table 2. The material extrusion rate increases along with the nozzle moving velocity in each group; however, it just fluctuates at first with the nozzle diameter rises and then goes up when the nozzle diameter exceeds 15mm. This implies that the rheology of material being deposited can change significantly when the nozzle diameter decreases to some extent, which makes it harder or even impossible for an undersized nozzle to extrude material. Values in Table 2 are inputted into *MATLAB* for fitting process. The nozzle diameter, the nozzle moving velocity and the material extrusion rate are severally denoted as x, y and z. The fitted function $z = f(x, y)$ is shown in Appendix A.

Table 2. Experimental matched values of the nozzle diameter, the nozzle moving velocity and the material extrusion rate.

Nozzle diameter (mm)	10	10	10	10	10	10	10	10	10	10
Nozzle moving velocity (mm/s)	10	20	30	40	50	60	70	80	90	100
Material extrusion rate (r/s)	0.4	0.5	0.6	0.7	0.8	1.0	1.2	1.5	1.8	2.2
Nozzle diameter (mm)	15	15	15	15	15	15	15	15	15	15
Nozzle moving velocity (mm/s)	10	20	30	40	50	60	70	80	90	100
Material extrusion rate (r/s)	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2
Nozzle diameter (mm)	20	20	20	20	20	20	20	20	20	—
Nozzle moving velocity (mm/s)	10	20	30	40	50	60	70	80	90	—
Material extrusion rate (r/s)	0.4	0.6	0.9	1.2	1.4	1.6	1.9	2.3	2.8	—
Nozzle diameter (mm)	24	24	24	24	24	24	24	24	24	24
Nozzle moving velocity (mm/s)	10	20	30	40	50	60	70	80	90	100
Material extrusion rate (r/s)	0.5	0.8	1.2	1.6	2.2	3.0	3.8	4.6	5.5	6.4

Note: The material extrusion rate is represented by the servo motor rotation rate of the depositing module of the VF3DCP extrusion kit.

3.2. Process test II

When a nozzle moves too fast along a tool path of a rather small curvature radius, torsion is very likely to occur in a filament. So, suitable nozzle moving velocities have to be applied to different tool path curvature radiuses, which depends on the functional relationship between the two key process parameters, fitted in this process test. A selected set of eleven one - fourth arc filaments with different curvature radiuses (40mm, 50mm, 100mm, 150mm, 200mm, 250mm, 300mm, 350mm, 400mm, 450mm, 500mm) is deposited using the 15mm nozzle diameter (the best working nozzle diameter in process test Ⅰ). The geometry conformity between the cross-sections of a filament and the nozzle is also manually checked by ruler measurements. The satisfactory arc filaments are presented in Fig. 5.

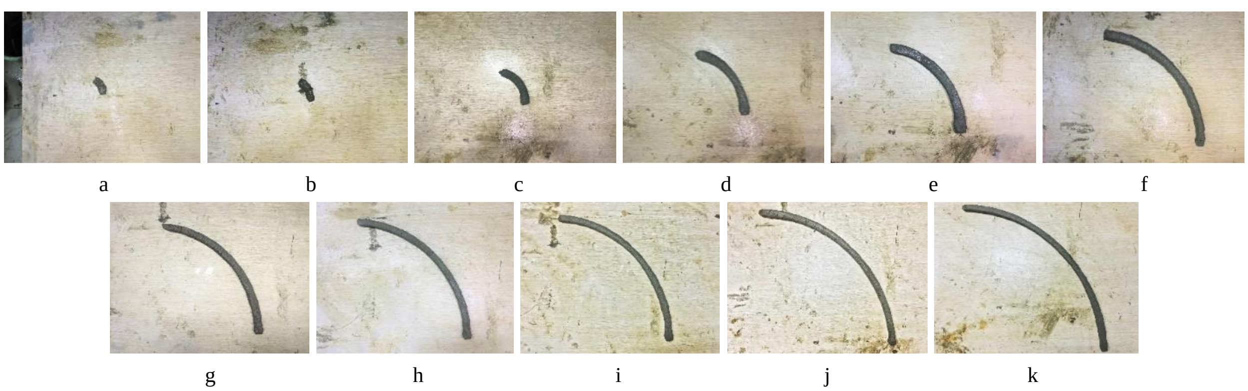

Fig. 5. Eleven one - fourth arc filaments deposited with different curvature radius, (a) 40mm; (b) 50mm; (c) 100mm; (d) 150mm; (e) 200mm; (f) 250mm; (g) 300mm; (h) 350mm; (i) 400mm; (j) 450mm; (k) 500mm.

The suitable nozzle moving velocities experimentally matched with the eleven curvature radiuses are recorded in Table 3. The nozzle moving velocities are finalized by most larger values under the premise of no torsions. Values in Table 3 are inputted into *MATLAB* to fit the functional relationship of the nozzle moving velocity and the tool path curvature radius, which are respectively denoted as y and r. The fitted function $y = g\ (r)$ is shown in Appendix B.

Table 3. Experimental matched values of the nozzle moving velocity and the tool path curvature radius.

Tool path curvature radius (mm)	40	50	100	150	200	250	300	350	400	450
Nozzle moving velocity (mm/s)	20	25	30	36	43	50	58	67	77	88

Combing the above two fitted functions, the functional relationship of *x*, *y*, *z* and *r* can be figured out as

$$z = f(x,\ y) = f[x,\ g(r)] \tag{1}$$

where *x* and *r* are dependent on the target geometry to be fabricated. However, Eq. (1) applies to the condition that both width and height of filament cross-sections constantly equal to the nozzle diameter, in which case the layer thickness will be variable within one layer due to variable nozzle diameter. To achieve constant layer - thickness manufacture, thinner filaments need to increase their cross-section heights to that of the thickest filament (denoted as *Dmax*) within one layer while their widths remain unchanged. In the light of equal volume principle, the nozzle moving velocity should be adjusted. Supposing the adjusted moving velocity and extrusion rate are *Y* and *Z*, *y* is replaced by *Y* with $y = Y*Dmax / x$ in the function $z = f(x, y)$. Then, we have $Z = F(x, Y)$ with $Y = g(r)$. Therefore, the final functional relationship of the four key process parameters for constant - layer manufacture is

$$Z = F(x,\ Y) = F[x,\ g(r)], Y \in [10, 100] \tag{2}$$

In Eq. (2), *Y* is valued as *10* if $Y<10$ and valued as *100* if $Y>100$. Other process parameters such as the rotation speeds of the turn-barrel and the rotary turntable are set up with suitable values to well support the VF3DCP process.

4. Case study: An architectural carve pattern

An architectural carve pattern is commonly used as an ornamental window (or door) or as an ornamentation to walls and facades (Fig. 1). It usually embodies a number of variable - width curve stripes in same thickness, which is a 2.5D geometry [19]. In the following, a typical architectural carve pattern is designed (Fig. 6) and fabricated by the VF3DCP method. The width of its inner stripes varies from 9mm to 24mm and that of its contour is 18mm.

4.1. Tool path generation

The VF3DCP adopts an adaptive tool path planning approach. The geometry of every curve stripe is calculated by a VF3DCP program to generate the stripe skeleton lines (central lines) as tool paths (with specific curvature radiuses) and also capture the variable widths of each stripe and the contour to determine the nozzle diameters. With the nozzle moving velocity and material extrusion rate figured out by Eq. (2), the nozzle is supposed to move along all the curve stripes and the contour in appropriate velocities with its changing diameter constantly equal to the widths of stripes and contour. The tool paths generating solution procedures are presented as follows.

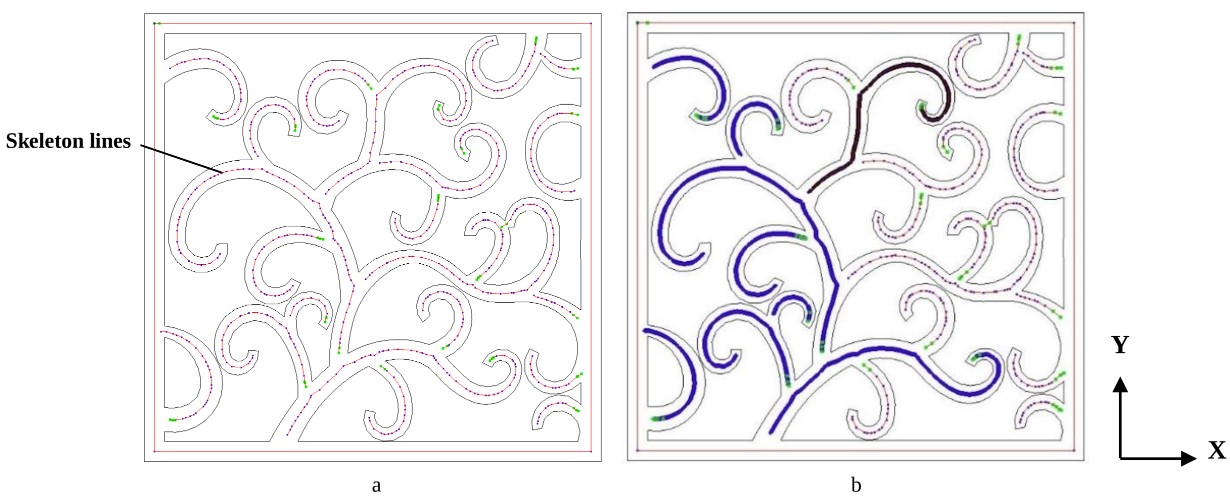

Fig. 6. (a) A designed architectural carve pattern with complete skeleton lines; (b) Tool paths planning (black stripe: current tool path being planned; blue stripes: tool paths that have been planned).

- *Step 1 - Initial skeleton lines generation*: A classical *Voronoi Diagram* algorithm [18] is first applied to the carve pattern, generating a number of the skeleton line-segments (red lines in Fig. 6a) with their pairs of endpoints (blue points in Fig. 6a) for all the inner stripes and the contour. A filtering treatment is done to discard those wrong line-segments outside of the stripe graphic entities, leaving all the correct line-segments connected to obtain the initial skeleton lines for this pattern. There are three types of endpoints in the initial skeleton lines - edge points, normal points and branch points, which respectively have one, two and three line-segments connected (Fig. 7).

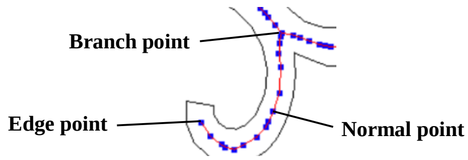

Fig. 7. Three types of endpoints in the skeleton lines.

- *Step 2 - Complete skeleton lines generation*: The initial skeleton lines need to be refined to reach final complete skeleton lines. For any two joint stripes (or contour), redundant skeleton line-segments that cause excessive material deposition at the branch point need to be removed. As shown in Fig. 8a, there are three successive line-segments along each branch from the branch point P_B with an end point (P_{N1}, P_{N2} and P_{N3}, respectively). In the pair of branch P_B P_{N1} and P_B P_{N2}, distances from the four intermediate normal points and point P_B to line P_{N1} P_{N2}, are represented by l_1, l_2, l_3, l_4 and l_5. These five distances are calculated and summed for each line, P_{N1} P_{N2}, P_{N1} P_{N2} and P_{N1} P_{N2}. A pair of branches that possesses the smallest summed-distance value would be kept connected at point P_B while the other branch would be pruned off by a certain length at its tail. Then, point P_B is transformed into a normal point (namely b-normal point) and point P_{N2} becomes a new edge point hereafter (Fig. 8b). As for the initially generated square contour, its four vertexes are distinguished by their maximal or minimal *x* / *y* coordinates among all the endpoints. These four vertexes would be successively lined to each other to generate a new contour which is much smoother. Therefore, the complete skeleton lines are figured out.

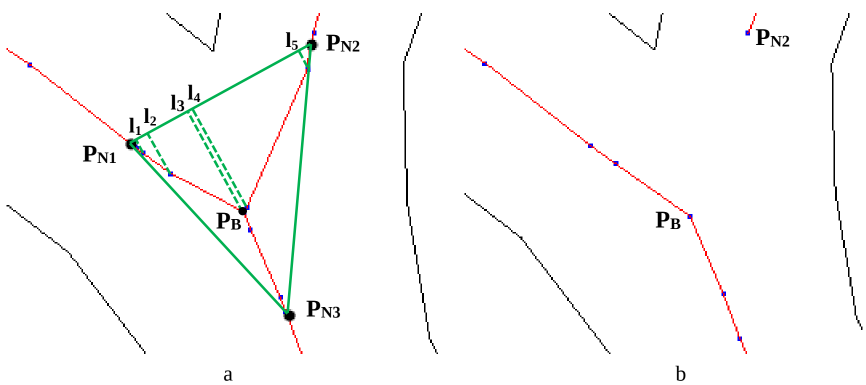

Fig. 8. (a) A branch point of two inner stripes; (b) Pruning of a branch.

- *Step 3 - Tool path planning*: The tool paths are planned along the complete skeleton lines, going from the inner curve stripes to the contour. For the stripes, a tool path is planned by traversal calculation, starting from an edge point that has the minimal *x* coordinate value among all the endpoints of unplanned paths and travelling through all the normal points (including b-normal points) until another edge point (Fig. 6b). Thus repeatedly, all tool paths can be planned from the area of small *x* coordinate values to the area of big ones. For the contour, a circle tool path would start from the vertex of minimal *x* coordinate and maximal *y* coordinate and also end up with it.

4.2. Pattern printing

The designed 2.5D carve pattern ornament is physically manufactured using the VF3DCP method with the trial material (Fig. 9). The curve stripes are printed before the square contour that encloses the stripes. During the printing process, two specific geometric features, the corner and the edge point, have been specially treated in that they have a significant impact on the overall print quality.

- *Corner*. A tool path contains a number of included angles (corners) between any two adjacent skeleton line-segments. These corners are separately treated for the inner stripes and the contour. For the inner stripes, the nozzle directly passes a corner from a former line-segment to a latter one while simultaneously rotating a required angle and depositing material. The rotation speed of the turn-barrel is set up as 450° /s, allowing the nozzle to instantly reach the right orientation for the latter line-segment. However, when the nozzle goes through a corner in the square contour, it would stop moving and depositing material but remain at the vertex to finish a rotation of 90° . Then the nozzle re-deposits material 0.1s ahead of re-moving to ensure continuous and ample material deposition.

- *Edge point*. A tool path starts from an edge point and ends up at another one. Given that the material is deposited from the nozzle onto the supporting surface, a time delay of nozzle movement is set up to obtain required material deposition in the beginning. On the other side, when the nozzle comes to a path end, its diameter is reduced to 3mm at a distance of 10mm (seen as green points in Fig. 6b) from the path end, aiming to cut off the filament in advance to obtain a neat end.

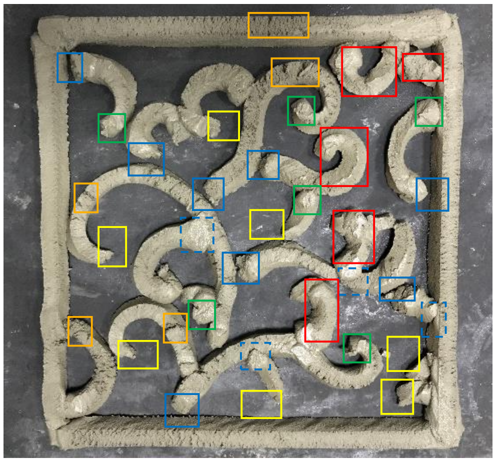

Fig. 9. The manufactured 2.5D pattern ornaments by the VF3DCP method.

Overall, the fabricated VF3DCP pattern looks close to its design (Fig. 6) despite the variable widths of curve stripes may seem somewhat inaccurate due to fitting errors of the functional relationships of the key process parameters. This pattern, however, is hard to manufacture by the conventional 3DCP process using a fixed-width nozzle. Some machine-based manufacture errors remaining to be solved in the future are presented as follows:

- *Accumulated error of included angles*: The current program allows no time for the nozzle to rotate at each corner with a curve stripe, which forces the nozzle to achieve a required rotation in the latter line-segment when it passes a corner. When the nozzle rotation speed is too low to finish the rotation within this line-segment, an error of included angle is generated and delivered to the next corner. Such errors are stripe-by-stripe accumulated from the start to the end, which leads to the skew and torsion of later-deposited stripes, especially those short stripes with high curvatures (red boxes in Fig. 9). Obviously, a higher rotation speed is supposed to alleviate the accumulated error of included angles while the current rotation speed of 450° /s is restrained by the machine capability.

- *Missed deposition at the beginning of a tool path*: The material in the nozzle will be deformed after a filament is cut off at the end of the last tool path. This claims for sufficient time for the nozzle to re-establish a steady state of material extrusion driven by the screw conveyer at the beginning of the current tool path. Inaccurate time delay control of nozzle movement at the start edge points results in missed depositions (yellow boxes in Fig. 9).

- *Deformation at the end of a tool path*: The nozzle can be reduced to no less than approx. 3mm when extruding the trial material for fear of getting stuck. However, this early reduction at the end of a path leads to the concrete filament being deposited cannot be completely cut off but dragged on a short distance and probably extended and warped a bit at its tail (green boxes in Fig. 9).

- *Disconnection or imperfect connection of two stripes*: Excessive punching of branches may cause some disconnections of two stripes where they are expected to be (blue boxes in Fig. 9). Some other connections of two stripes are unsatisfactory where the joints hardly appear in designated profiles (dashed blue boxes in Fig. 9) since the nozzle cannot change its shape other than square to fit different joint profiles.

- *Surface cracks of stripes*: The material is extruded by a screw conveyer which offers much less pressure compared to a screw pump. So, it is no doubt that there are apparent cracks on the stripe surfaces (orange boxes in Fig. 9).

5. Discussion and conclusions

This study aims to demonstrate a novel VF3DCP process to manufacture architectural ornaments through a case study of pattern manufacture, forgiving some manufacture errors. The mechanical functional relationships fitted through the two process tests are specifically applied for the developed VF3DCP extrusion kit prototype and the trial material; new mechanical functional relationships have to be determined if the VF3DCP machine and material are changed. However, the proposed VF3DCP method still shows an exciting possibility to construct architectural ornaments.

The VF3DCP is not just a remarkable technology but reveals a whole new way of thinking to take advantages of the 3DCP technology to make a difference to the architecture, engineering and construction community. Above all, it brings higher manufacture efficiency to the 3DCP process. Apparently, it will take much less time to manufacture a large-scale part during printing if the nozzle diameter is improved from a small value to a bigger one on the premise of required surface resolution. Since the nozzle developed in this VF3DCP extrusion kit prototype is designed up to 25mm in diameter, nozzles of larger diameter ranges as 0-100mm, 0-200mm, or even 0-1000mm can be expected as long as problems of material delivery and mechanical capability can be solved. This means an entire component can be manufactured in one-time printing work, which sharply raises productivity.

In addition, the VF3DCP method is expected to greatly enrich the product complexity and diversity. The 2.5D architectural pattern in the case study is achieved by the VF3DCP process that only changes the nozzle diameter during printing. This is accomplished within the horizontal plane, which refers to a two-dimensional volume variation dependent on the constant layer - thickness slicing condition. If a variable layer - thickness slicing algorithm is applied along with a special tool path planning algorithm, the VF3DCP process will be able to change the nozzle height when it is varying its diameter, contributing to three-dimensional volume variation printing, a genuine volume - forming fabrication process. In that context, more ornaments of complicated geometries and other components with architectural ornamentations are reachable, making the 3DCP more flexible and feasible for the future industry.

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Appendix A.

The fitted function is:

$$z = f(x, y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3 + p31*x^3*y + p22*x^2*y^2 + p13*x*y^3 + p04*y^4 + p32*x^3*y^2 + p23*x^2*y^3 + p14*x*y^4 + p05*y^5$$

p00 = 8.437 (4.23, 12.64) *p10* = -1.486 (-2.287, -0.685)
p01 = -0.3316 (-0.5524, -0.1109) *p20* = 0.08331 (0.03484, 0.1318)
p11 = 0.05733 (0.01865, 0.09601) *p02* = 0.003522 (-0.0006504, 0.007694)
p30 = -0.001477 (-0.002415, -0.0005378) *p21* = -0.002985 (-0.005233, -0.0007379)
p12 = -0.0003979 (-0.000873, 7.719e-05) *p03* = -2.895e-05 (-9.121e-05, 3.331e-05)
p31 = 4.934e-05 (6.834e-06, 9.185e-05) *p22* = 1.262e-05 (-1.107e-05, 3.631e-05)

p13 = 1.479e-06 (-8.313e-07, 3.788e-06)
p04 = 2.234e-07 (-3.267e-07, 7.735e-07)
p32 = -2.211e-08 (-4.317e-07, 3.875e-07)
p23 = -3.247e-08 (-8.037e-08, 1.543e-08)
p14 = -2.799e-09 (-1.07e-08, 5.103e-09)
p05 = -7.45e-10 (-2.671e-09, 1.181e-09)
(with 95% confidence bounds)

The goodness of fit:
SSE: 0.05351; R-square: 0.9993; Adjusted R-square: 0.9987; RMSE: 0.05048

Appendix B.

The fitted function is:

*y = g (r) = p1*r^9 + p2*r^8 + p3*r^7 + p4*r^6 + p5*r^5 + p6*r^4 + p7*r^3 + p8*r^2 + p9*r + p10*

p1 = 5.805e-20 (-5.434e-20, 1.704e-19)
p2 = -1.47e-16 (-4.085e-16, 1.146e-16)
p3 = 1.596e-13 (-9.847e-14, 4.176e-13)
p4 = -9.712e-11 (-2.38e-10, 4.378e-11)
p5 = 3.629e-08 (-1.03e-08, 8.288e-08)
p6 = -8.567e-06 (-1.816e-05, 1.03e-06)
p7 = 0.001265 (4.423e-05, 0.002486)
p8 = -0.1111 (-0.2027, -0.01943)
p9 = 5.281 (1.628, 8.934)
p10 = -75.87 (-134, -17.69)
(with 95% confidence bounds)

The goodness of fit:
SSE: 0.009155; R-square: 1; Adjusted R-square: 1; RMSE: 0.09568

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A study of the possibility of using ground waste glass as a replacement for cement in cement composites

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Abstract

The paper presents the results of tests of cement composites in which a glass substitute derived from municipal waste was used as a partial replacement for cement. The tests used a glass cullet made of brown glass, which after rinsing to remove sugars and other impurities, was dried and ground to a fraction below 125 μm. Cement mortar samples were made, in which cement was replaced with: 3, 5, 10 and 20% of glass powder. Heat of hydration of the paste and the consistency of fresh mortars and mechanical properties of mortars after 28 days of curing were analyzed. The best results were obtained for mortars with a 5% share of glass powder. The research shows that the binding properties of glass powder are closely related to the degree of grinding of the waste, and when significantly ground, they may exhibit pozzolanic properties.

Keywords: cement composites, ground waste glass, recycling, mechanical properties

1. Introduction

Glass, being an inert material, is commonly used for the production of packaging. Glass recycling in Europe is among the most advanced in the world. In some European countries, nearly 85 % of glass packaging, especially bottles and jars, are made from recyclate. Glass that is made of sand, a commonly occurring raw material, can be melted many times without losing its value. Unfortunately, these advantageous features of glass packaging, especially in the terms of used packaging and glass cullet formed from them, are not rationally used in Poland. Industrial cullet associated with the technological process of glassware production in Poland is about 28 % of the total amount of cullet possible to re-use [1]. Cullet, which comes from car windows, from "safe" glass or from CRT glass is a particularly serious problem. These types of cullet are not used by glassworks and other ways of their utilization have to be found.

When assessing the possibility of using waste glass in the construction industry in terms of its impact on the natural environment, some benefits can be observed. Primarily the reduction of the storage of waste material can be mentioned. There is also the possibility of the use of the waste glass as a substitute of materials derived from natural resources. The waste glass used for concretes does not significantly affect the level of environmental impact of the obtained material. An exception may be glass cullet coming from CRT glass, containing significant amounts of heavy metals [2].

Waste glass in the construction industry is used, for example, for the production of mats and insulation boards, grits for plaster, as an addition to ceramic masses, mortars and cement concretes [3-8].

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In the case of the use of waste glass in cement composites, the replacement of natural fine aggregate with fine ground glass cullet has proved to be the most effective so far [9-10]. Research [11] has shown that the use of the waste glass as a coarse aggregate may worsen the mechanical properties of cementitious composites due to the cracking of the larger grains.

The paper presents the results of cement mortar tests, in which the waste glass from brown glass was used. The waste glass was ground to a fraction with a maximum grain size ~~of~~ 125 μm. The glass powder, prepared this way, was used in the tested mortars as a sealing admixture and a cement replacement.

2. Materials and methods

2.1. Materials

Cement mortar was made using Portland cement CEM I 42.5R (according to PN-EN 197-1), fine aggregate and tap water. The fine aggregate was CEN standard quartz sand with a grain size compliant with the requirements of PN-EN 196-1. Glass powder was prepared from the glass waste obtained from a local recycling company. Prior incorporation to cement mortars, the waste glass was washed in water (in order to remove contaminants), dried and ground to obtain a glass powder with a maximum grain size ~~of~~ 125 μm. The gradation curve was conforming to PN-EN 196-1. Table 1 presents the chemical composition of waste glass used. Fig. 1 shows a SEM photography of the waste glass after milling process.

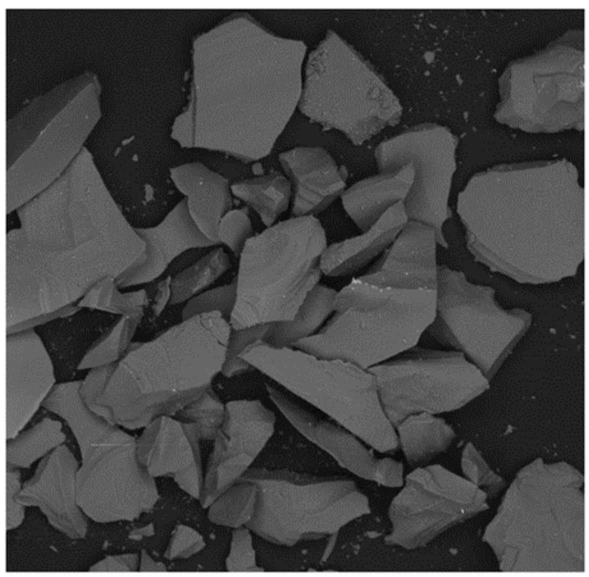

Fig. 1. SEM photography of the waste glass after milling process.

Table 1. Chemical composition of the waste glass.

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O
Content [%]	71.51	1.69	1.66	10.24	1.64	0.07	0.55
Component	Na_2O	P_2O_5	TiO_2	Mn_2O_3	SrO	BaO	
Content [%]	12.35	0.02	0.21	0.05	0.02	0.56	

2.2. Mixture composition and mortar preparation

Cement mortars with the constant aggregate to cement to water ratio 3:1:0.5 were prepared according to the PN-EN 196-1. Two groups of cement mortars were prepared. The first group of cement mortars was designed as R (reference mortar). Digits 0, 3 and 5 next to the name of the mortar indicated the percentage content of the glass powder, in relation to the cement mass. The second group of mortars were marked as M10 and M20. In these mortars 10 % and 20 % of the mass of the cement was replaced with glass powder, respectively. The composition of the tested mortars is presented in Table 2. After demoulding, the mortars were stored at 20ºC ± 2ºC and relative humidity RH ≥ 95 % for 28 days.

Table 2. Mixture compositions and consistency of fresh cement mortars.

	Unit weight [kg/m^3]				Consistency
Sample designation	Cement	Water	Sand	Glass powder	Mean diameter [mm]
R0	519	257	1546	-	165
R1	519	257	1546	15.5	150
R3	519	257	1546	26.0	147
M10	467	257	1546	52.0	155
M20	415	239	1546	104.0	163

2.3. Test methods

The consistency of cement mortars was tested by a flow table according to PN-EN 1015-3. Flexural strength and compressive strength of mortars were determined in accordance with PN-EN 197-1 after 28 days of curing. Six prisms in size of 40 x 40 x 160 mm were prepared for each type of mortar for the determination of strength. Water absorption test, by soaking, was conducted in accordance with PN-B-04500:1985. For this test 3 prisms of each type of mortar in size of 40 x 40 x 160 mm were used.

3. Results and discussion

Table 2 and Fig. 2 present the consistency of fresh cement mortars determined by the flow table method. The addition of the glass powder had a slight effect on the deterioration of the consistency of R3 and R5 mortars, and both mortars maintained their workability. The use of glass powder as a cement replacement did not significantly affect the consistency of the mortars, and in the case of M20 mortar, the consistency obtained was similar to the consistency of the reference mortar R0.

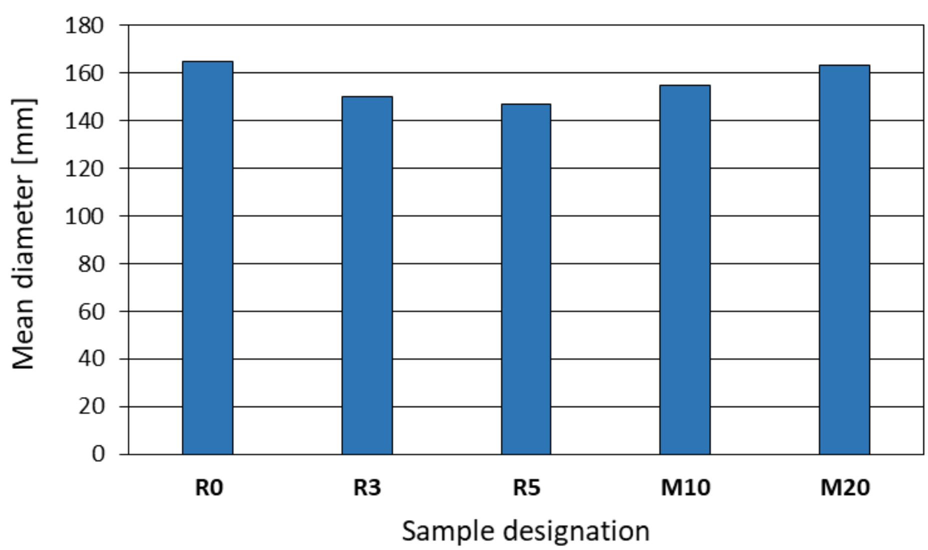

Fig. 2. Consistency of fresh cement mortar.

Fig. 3 presents the results of the mass absorption testing of mortar samples. Addition of the glass powder slightly improves the absorption resistance of the tested mortars. However, for the M20 mortar, water absorption similar to the reference mortar R0 was obtained.

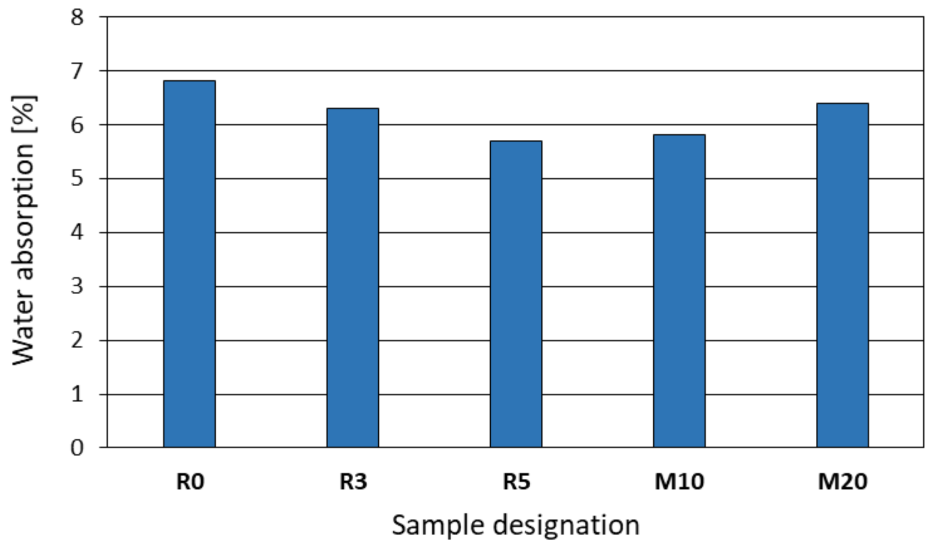

Fig. 3. Water absorption of cement mortars.

Fig. 4 and 5 present flexural and compressive strength after 28 days of curing, respectively. The use of the waste glass did not significantly affect the flexural strength of the tested mortars. For R5 mortar, a slight increase in flexural strength by 1.5 % was observed. This may be related to the sealing of the composite structure by the glass powder. The use of the waste glass as a cement replacement resulted in a reduction of the flexural strength of the mortars by 9 % and 14 % for mortar M10 and M20, respectively.

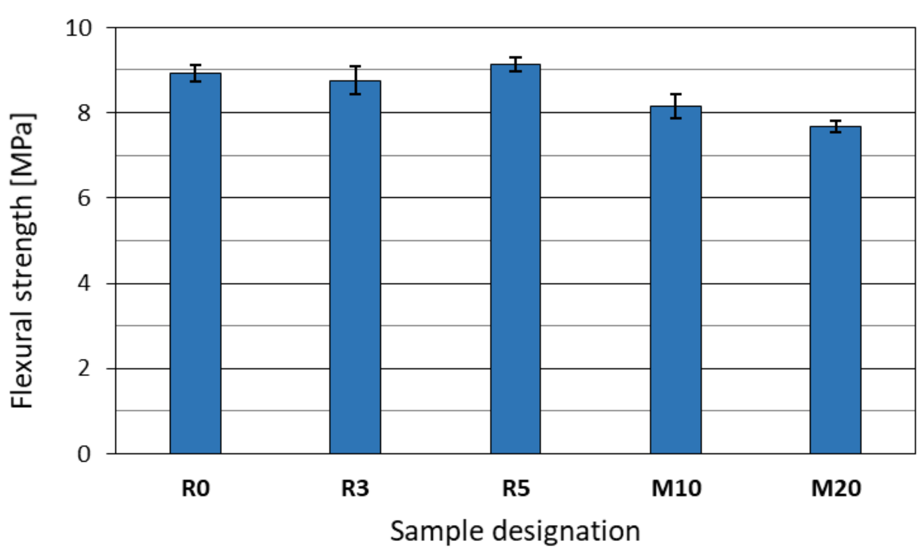

Fig. 4. Flexural strength of cement mortars after 28 days of curing.

The compressive strength of the tested mortars decreased with the increase of the content of the waste glass in the mortar. The use of the glass powder as an admixture caused a slight decrease ~~in~~ of strength by 3.7 % and 2.5 %. However, for mortars M10 and M20, the decrease of compressive strength was 14 % and 20 %, respectively. The low grinding degree of the glass powder could be the reason for its negative effect on the compressive strength of the tested mortars. As shown by research [12], when using 20 % glass powder (as the cement substitute) of fractions up to 40 µm, the mortars obtained compressive strength similar to the reference mortars. The use of the glass powder of fractions 80-100 µm resulted in a compressive strength drop by 20-23 %, regardless of the color of the glass used.

The best properties were obtained for R5 mortar, with 5 % content of the glass powder. It had good workability, high flexural strength and slightly lower compressive strength in comparison to the reference mortar R0.

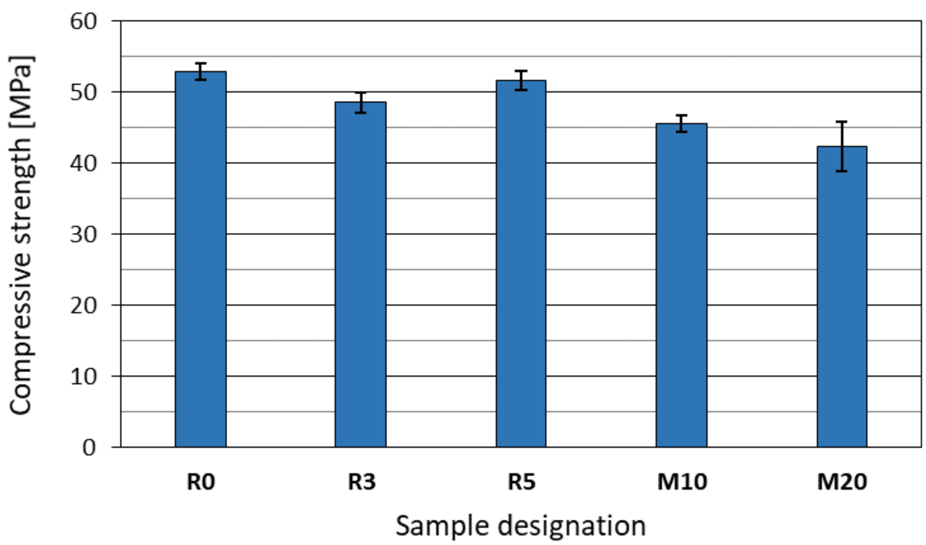

Fig. 5. Compressive strength of cement mortars after 28 days of curing.

4. Summary

The paper presents the experimental results of investigations of the cement mortars modified with a variable amount of the glass powder of fractions up to 125 um. Based on the obtained results, it was assessed that the idea of using the glass powder derived from the waste glass for the modification of the composition of cement mortars is promising. The addition of the glass powder in the amount of 5 % of the cement mass resulted in the structure sealing, smaller water absorption and the improvement of the workability of fresh mortar while maintaining its mechanical properties after 28 days of curing.

The use of the glass powder as a cement replacement in the amount of 10-20 % does not reduce mortar workability, however, it causes deterioration of the mechanical properties of the mortar. The improvement of mechanical properties can be obtained by using glass powder with a smaller diameter of the maximum fraction, which is confirmed by research [12].

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A Study to Investigate Using Mobile Devices in the Construction Management Classroom as Rationalized by the Needs of Industry

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Abstract

The construction management (CM) curriculum is constantly adjusting to keep pace with changes and developments in industry. Often times, CM programs will make use of an industry advisory committee to make sure that the program remains relevant and is aligned with the needs of industry. Technology is a common subject when faculty and industry professionals converge. At times the path is clear for what needs to be done, and other times no real direction is provided to make sure that universities are doing what is necessary to meet the needs of industry. In this study, a detailed survey was administered to industry professionals with the intent of using this data to inform CM academic programs in terms of what mobile device would be best to use. Eventually, this data will prove useful in helping faculty design course curricula to include the right kind of mobile device for the right type of learning activity.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2018.

Keywords: mobile technology; active learning; construction education

1. Introduction

Preparing for new advancements in technology can be difficult, especially when there are many factors involved in evaluating them. An especially useful technology involves mobile devices that are so convenient that they have become an integral part of our personal lives. There are a myriad of devices available, each differing in size, capability, color, form-factor, price, manufacture and so on. These preferences make the task of evaluating and selecting a mobile device cumbersome. Additionally, these preferences can be deeply rooted in personal choices, further complicating a selection effort. Manufacturers have caught on to these challenges and have produced mobile devices that cater to the needs of virtually everyone. While this may be good for the consumer, it has been difficult for businesses that want to standardize their solutions to adapt. Businesses recognize that mobile devices can save time and provide much needed data to employees. However, businesses benefit most when the technology that they employ fits neatly into their information infrastructure. The constant design and feature churn in the new releases of mobile devices makes implementing them problematic. Unfortunately, businesses are not the only entities that struggle to implement mobile devices.

Academia is constantly creating learning experiences that mimic the experiences one has while in industry. This can be achieved through traditional class discussions, lectures and assessments, however, when technology is involved, the learning experience is enriched through a more active approach to teaching and [1]. Active learning engages students in such a way that they can begin to ask the "why" questions about their learning experiences [2]. It is important that academia teaches with the same types of equipment and resources that students will use in industry after

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they graduate. Therefore, it is not unreasonable to assume that academic institutions will struggle with similar mobile device decisions, much like their industry counterparts.

This research was conducted so that academic programs could prepare graduating students for a mobile working environment. Other benefits of this study illustrate how incorporating mobile devices in the construction management (CM) classroom increases active learning and student engagement. Lastly, mobile devices are the platform for other emerging innovative technologies, therefore, an academic program that incorporates course work that requires the use of mobile devices is preparing those students for the future construction industry workplace.

2. Research Motivation and Past Research

The construction management curriculum of today is focused on molding students to think creatively about ways to solve challenging problems. Changes within the industry, such as, the introduction of sustainability standards, increased safety protocols and the use of building information modeling (BIM) are creating an environment where creative thinking and resourceful problem solving reward businesses by setting them apart from their competitors [3]. Colleges and universities face a challenge in preparing students (and the future workforce) to be creative thinkers. The conventional classrooms are built around agrarian and industrial era models that are not well suited to teach students of the 21st century [4,5,6]. In order to achieve a higher degree of learning and a deeper understanding, students need learning environments that foster active learning above traditional passive learning models and according to Cardullo [4], they will also need the right tools in the classroom to make this transition possible. As the renowned 20th century visionary and inventor, Richard Buckminster Fuller stated,

> "If you want to teach people a new way of thinking, don't bother trying to teach them. Instead, give them a tool, the use of which will lead to new ways of thinking."

Research indicates that mobile technology allows for the "acquisition of knowledge regardless of location and time" [7]. The research further indicates that the proper use of mobile technology in the classroom can improve certain educational outcomes [1,8]. This fact coupled with the ubiquity [1] of mobile devices already in the hands of many students supports a motivation for using these devices in the classroom. Likewise, the academic community is aware of the success of mobile devices within the management of projects through numerous case studies and articles. Consequently, there is growing interest in mobile device research at academic institutions across the U.S., therefore, it is imperative to adopt an approach toward mobile device selection for academic institutions based on the same rigors that industry uses.

Mobile technology is seeing strong growth in the construction industry and this trend continues to rise [9,10,11]. For construction academics to remain relevant there must be a response to this interest in mobile technology. Demand for more mobile technologies in the classroom may be driven by the incoming student's themselves [9,12,13,14]. While this statement could arguably be applied to any curriculum at any learning institution it is important to note that it is particularly relevant to the needs of the construction industry and those that would prepare its future workforce. As early as 1993, Opfer acknowledged that the construction industry was a *mobile environment*. An environment where most of the participants were not confined to a single location, such as the case for the manufacturing industry. The environment of the construction site is *dynamic* and not *static* and mobile devices offers an opportunity to support these characteristics of the construction industry [15]. Therefore, connecting the need to educate students in classrooms more befitting of the 21st century with the needs of the construction industry sets the direction for this research.

There have been many studies that investigate the benefits and challenges of active learning and the use of mobile technology in the classroom and many report the results of ways in which it should happen. A useful connectedness between student learning objectives and mobile devices would provide instructors with a blueprint for incorporating more mobile, active and student centered pedagogy in the CM classroom. This research will focus on exploring the various uses of mobile devices within the construction industry with the overall intent to inform the CM classroom on ways in which it can be used to better prepare graduating students. The following research questions will be addressed through this study:

- What purchase criteria are important when considering mobile devices?
- What are the current workforces' perceptions regarding mobile devices?
- How does the current workforce use mobile devices?
- What applications and features are most useful when using mobile devices?

3. Methodology

In order to prepare students for the construction working environment, it is best to give them experiences at school that are similar to those that they will face when in industry. Likewise, the tools that they use should match the tools used in industry. Therefore, the focus for this research is on matching the preferred mobile device types that industry uses with those that should be used in the CM classroom. This research was designed to obtain feedback from industry concerning their experiences and perceptions about mobile devices. An electronic survey was distributed via email to construction industry advisors of the McWhorter School of Building Science at Auburn University. Additionally, the survey was made available through social media outlets of the Associated General Contractors Alabama Chapter and the Associated Builders and Contractors Georgia Chapter. 177 responses were received, however, in order to ensure relevance and consistency within the responses, 32 responses were rejected for the following reasons: 1.) the participant was not easily categorized as a member of an industry capable of providing relevant feedback for this study or 2.) the response to the survey was incomplete. This survey included both closed and open-ended questions designed to respond to the aforementioned research questions.

4. Results

4.1. Demographics

The participants in this survey were 86% male and 14% female and ranged in age from 44% classified as *Baby Boomers* (1941-1965), 37% *Generation X* (1966-1980) and 19% *Generation Y* (1981-2000). Within the built environment, 24% identified as owners, 60% as builders (or trade crafts), 15% as designer/engineers and 6% as other. Participants reporting 1-5 years of work experience (6%), 6-10 years (11%), 11-20 years (22%) and 20 years or more (60%). Lastly, organizations ranged in size (in terms of annual revenue) *Less than 1 million* (4%), *1 million to 10 million* (15%), *10 million to 25 million* (18%), *25 million to 100 million* (20%) and *100 million and above* (43%).

4.2. Questions regarding mobile device selection criteria

The purchase decision alone can be a daunting task for mobile devices when one considers all of the available options. When participants were asked to sort their preferred criteria for selecting a mobile device, they ordered their decisions in the following manner:

1. Most important - *Quality*
2. Important - *Price*
3. Somewhat Important - *Manufacturer*
4. Least Important - *Word of Mouth*

Quality, as the most important factor, is difficult to assess and may be a subjective variable, therefore, participants were asked about ruggedization of the device as a factor of quality that could be relatable to the construction industry. 61% of participants responded that they would prefer to have a ruggedized device and for those that indicated otherwise, a combined 88% of that group indicated that they would (*Definitely yes* to *Probably yes*) buy a ruggedized case to protect their mobile device.

Participants were asked to identify a price range that they considered *average* for the type and size of mobile device that they preferred:

- 6% - Less than $300
- 14% - $300 - $400
- 21% - $400 - $500
- 20% - $500 - $600
- 22% - $700 - $800
- 7% - $800 - $900
- 10% - More than $900

There is a wide selection of manufacturers to choose from for mobile device. Deciding on a mobile device based on the manufacturer is an important decision because by selecting a manufacturer you are devoting yourself to an operating system and a marketplace for available applications (apps) to run on the device. Participants ranked the preferred manufacturers in the following order:

1. Most Preferred - *Apple*
2. Preferred to Somewhat Preferred - *Microsoft, Samsung and Google*
3. Least Preferred – *Blackberry*

When asked about the ownership of the mobile device, 69% indicated that the company owned the device, 18% indicated that the employee owned the device but was compensated for its work-use and 7% used their own personal device without being compensated.

4.3. Questions regarding the current workforces' perceptions regarding mobile devices

Participants were asked about their habits and attitudes regarding the use of mobile devices, the details of which have been summarized in Figure 1. When asked how often they worked away from a fixed office location, 51% of the participants responded *Often* with only 2% responding *Never*. The participants were asked to rate the perceived effectiveness that mobile devices had on cost, time and quality of work. In terms of a cost benefit, a combined 96% indicated yes (*Definitely Yes* to *Probably Yes*) while the remaining 4% indicated that there may not be a cost benefit. Considering if mobile devices save time, a combined 98% indicated yes (*Definitely Yes* to *Probably Yes*) while the remaining 2% indicated that there may not be a time savings benefit. Lastly, when asked if mobile devices benefited the quality of work, 43% indicated *Definitely yes*, 31% indicated *Probably yes*, 20% indicated it *Might or might not*, 4% indicated *Probably not* and 2% indicated *Definitely not*.

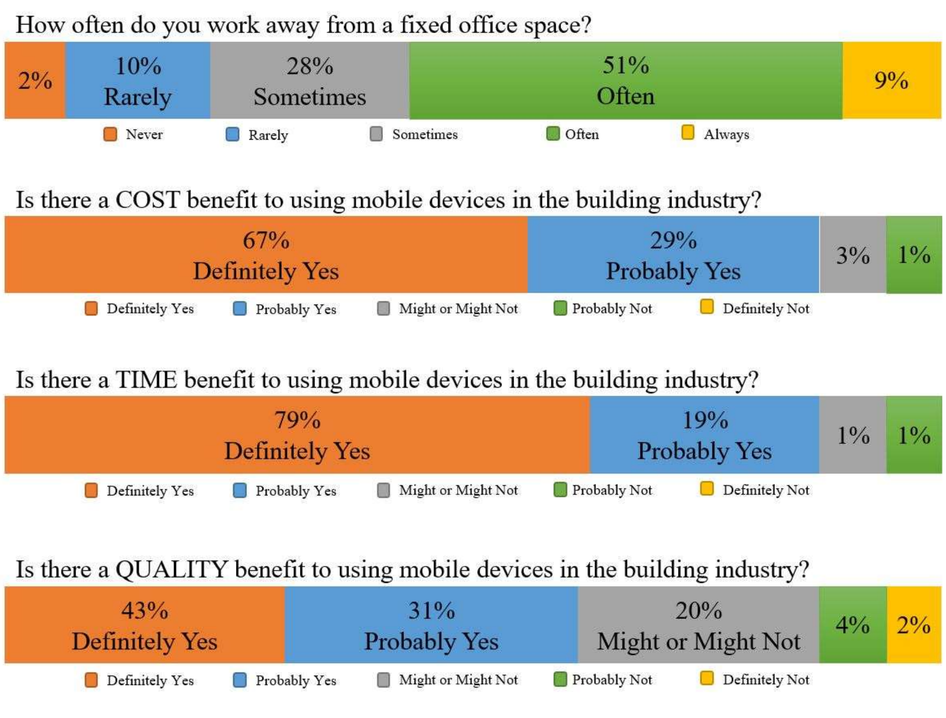

Fig. 1. Habits and attitudes regarding the use of mobile devices.

Because so many participants indicated that they partly worked away from a fixed location, when further asked if they relied on a mobile (tablet sized) device when away from their fixed office location, 9% responded *Always*, 32% responded *Often*, 29% responded *Sometimes*, 16% responded *Rarely* and 14% responded *Never*. Lastly, the participants were asked if a mobile device could replace their laptop or desktop computer and 4% responded *Always*, 16%

responded *Most of the time*, 37% responded *About half of the time*, 39% responded *Sometimes* and 5% responded *Never*.

4.4. Questions regarding the current workforces' use mobile devices

Mobile devices are a part of many different processes within the construction industry. Participants were asked to rank these processes by considering how impactful mobile devices were to the success of that process. The following list represent those processes in order of most impactful to least impactful.

1. Project Management and Document Administration
2. Project Supervision and Work Coordination
3. Scheduling
4. BIM and VDC
5. Preconstruction and Cost Estimating
6. Accounting and Cost Management
7. Design and Engineering
8. Safety and Risk Management
9. Project Compliance

Participants were asked which age groups seemed to make the most use of mobile devices, 66% responded *Employees aged 26 - 35* and 23% responded *Employees aged 20 - 25* while only 2% responded *Employees older than 45.* Lastly, participants were asked to consider recently graduated students that have become junior level employees and rate their overall mobile device proficiencies. 31% responded *Extremely well*, 33% responded *Very well*, 29% responded *Moderately well*, 5% responded *Slightly well* and 2% responded *Not well at all*.

4.5. Questions regarding mobile device applications and features

It is important to note that the mobile device is a platform for running apps. These apps and native features are what create the usefulness of the mobile device. Participants were asked to provide some feedback on the features and apps that they found most useful in their mobile device. The open-ended responses were coded and categorized and are summarized in the table below (Table 2.).

Table 2. Preferred Features and App Categories

CATEGORY	**Frequency (%)**
Email	81 (14%)
Camera	69 (12%)
Productivity App	49 (9%)
PDF Management App	47 (8%)
Project Management App	44 (8%)
BIM App	36 (6%)
Plan Management App	33 (6%)
Map	29 (5%)
Cloud Storage App	28 (5%)
Web Browser	24 (4%)
Text Messaging	20 (3%)
Weather App	20 (3%)
Calculator App	15 (3%)
Video Communication App	15 (3%)
Accounting App	14 (2%)

Note Taking App	14 (2%)
Calendar	12 (2%)
Field Management App	9 (2%)
Scheduling App	8 (1%)
Safety App	7 (1%)

5. Discussion

5.1. What purchase criteria are important when considering mobile devices?

As previously stated, when purchasing mobile devices, there are several criteria to evaluate - often complicated through personal preference and bias. The data seem to indicate some personal bias may be present when the participants select “Quality” as the highest consideration. Quality is a subjective [16] decision and can be easily swayed by outside factors that are not easily comparable when making a purchase decision. However, the second most common consideration was “Price”. A consideration that can easily be measured for a purchase decision. It is important to note that a low ranking received by the “Manufacturer” purchasing consideration was offset by the overwhelmingly high ranking for Apple products as the “Most Preferred” manufacturer. There are no conclusions about this distinction in this data and it should be explored further in future iterations of this research. “Price” was highly considered as a purchase decision and participants were almost evenly grouped in their preference about what price they would be willing to pay for the mobile device, 21% preferred $400-$500, 20% preferred $500-$600 and 22% preferred $700-$800. When considering the preferred price for a mobile device, the data indicate that the range is somewhere between $400 and $800. In terms of the size of organizations that are making these purchase decisions, it could be assumed that with a price point between $400 and $800, these mobile devices are regarded more as consumable equipment rather than durable, long lasting equipment.

Lastly, the participants were asked if they owned the mobile device or if their company owned the device. The majority of participants indicated that the company owns the device. As the use of mobile devices becomes more commonplace, the need for businesses to offer them as a way of keeping their employees mobile and able to access the most up-to-date data will increase. This presents security problems for businesses as their data is now spread thinner across more devices. Additionally, businesses prefer to operate with some standards and by controlling the devices (through ownership) they can also control the types of devices that are used to access their data. Similarly, universities will be concerned about security breaches and standardization of devices. Therefore, it is advisable to align a purchase decision about mobile devices, in the same manner as industry.

5.2. What are the current workforces’ perceptions regarding mobile devices?

This research question is important because it gauges how the workforce perceives the importance of mobility and if it practices it. Understanding this perception can help academia structure more curricula that is aligned with the business practices of industry. 51% of the participants indicated that they “often” work away from a “fixed” office space (Figure 1.). Most (a combined 41%) also indicated in a follow up question that they use a mobile device when they are away from their office. There is consistency with these results and those found in another industry wide survey conducted by JB Knowledge [11] that reveals an increasing trend in the use of mobile devices within industry. These results support industry’s increasing reliance on mobile devices and should not be overlooked by academia when considering incorporating mobile devices in the CM classroom curricula.

Participants of this study were asked to provide their perceptions regarding cost, time and quality when using a mobile device. There were significant cost and time benefits as perceived by the participants, however, in terms of quality, the results were muted (Figure 1.). Participants also responded to the interchangeability of mobile devices with their laptop and/or desktop computing devices. These results were also muted in that the majority of participants only *Half of the time* (37%) or *Sometimes* (39%) used a mobile device as a replacement to their laptop and/or desktop. The only distinction that can be presumed here is that there are still some work tasks that the participants were unable to clearly attribute to quality through the use of a mobile device and some work tasks are still only achievable with legacy computing devices.

5.3. How does the current workforce use mobile devices?

The participants were asked to identify the age group of employees that seemed to make most use of mobile devices in their company. A significant number (66%) indicated a group of employees that had been with the company at least five years (age group 26-35) were more adept at using mobile devices. This indicates that there is a period of time in which employees develop a mobile proficiency in their work tasks. Perhaps a period of time is necessary to gain experience before the employee is considered effective as a mobile device user. Notwithstanding, the participants did indicated that the graduating students are exhibiting mobile device proficiencies (a combined 64% responded *Extremely well* to *Very well*).

5.4. What applications and features are most useful when using mobile devices?

Mobile devices are built to bring utility in a way that is convenient to the end user. They achieve this utility through the various features that are built into the devices and through the many apps that can be added to them later. Because this is an important part of mobile devices, this survey asked the participants through open-ended feedback to define as many features and apps they found useful when using their mobile device. 574 features and apps were recorded by the participants. The responses were coded and categorized to reveal the most frequently used features and apps (Table 2.). It is not surprising that “Email” and “Camera” use topped the list with 14% and 12% respectively. Productivity apps such as a word processor or spreadsheet application were third in the list. A continued review of the list in Table 2., and it becomes apparent that the most frequent uses for the mobile device are similar in nature to those applications found on a laptop or desktop computer. This makes a strong case for the replacement of those legacy computing devices over time and an indication that training at academic institutions with the use of mobile devices is essential.

6. Conclusion

This study has focused particular attention on the perceptions of industry and how they are making use of mobile devices. It should be noted that the cross section of the industry analyzed was very narrow, in fact, it is characteristically industry members from the Southeastern United States. However, in terms of the scope of this research, there is ample data to start the development of a curriculum that includes elements of mobile technology in order to improve the skill set of graduating students. It is advisable to increase the research population to overcome regional attitudes toward technology use within the industry. For instance, in a McGraw-Hill SmartMarket Report on BIM technology, the West and Midwest regions of the United States have an adoption rate of 77% and 73% respectively compared to the South which had a 68% adoption rate [17]. A similar attitude toward mobile technology use could exist and needs to be validated with further research.

The objective of this research in preparing the graduating student for the future workforce would not be complete if the needs of industry were ignored, therefore, an understanding of how industry uses mobile devices was an additional motivation for this study. The study provided some insight through the various uses that participants shared through an open-ended response. As these responses were coded, it became apparent that they could be mapped to student learning objectives tied to course learning objectives and thereby become an integral part of an academic program. This list of feature and apps (Table 2.) should be researched further in order to initiate the implementation of mobility in the CM classroom.

Overall, the demographics of this study included some members from industry that have a significant amount of experience and it is apparent from their responses that they value what mobile devices can bring to the industry in terms of productivity. Consequently, in much the same way that building information modeling dispersed throughout the industry, so too can the use of mobile devices. While we are seeing this now, as evidenced by the survey responses, there seems to be a lack of some truly innovative uses for mobile devices. There was no mention of mixed reality, coordination with drones was only scarcely mentioned and BIM was 6th on the list of most used features and apps. It will require the next generation’s conviction to innovate - but they cannot begin that process if they are not exposed to it at some level while they are still in school. This point is best illustrated by John Dewey in *Democracy and Education*, where he predicted that “if we teach today's students as we taught yesterday’s we rob them of tomorrow” [18].

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Advantages and Disadvantages of Trenchless Construction Approach as Compared to the Traditional Open Cut Installation of Underground Utility Systems

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Abstract

The construction industry in North America is faced with the ongoing task of incorporating new technologies and management methods into their operations. New technologies and methods generally receive acceptance very slowly due to a number of factors. The risk of applying a new or unproven technology or method is sometimes perceived as being too high. Trenchless methods allow inspection, access, repair, expansion, upgrade, and installation of most underground infrastructure systems with minimum surface disruption. The tools that trenchless technologies offer range from robots to microtunneling and from closed-circuit television to cured in-place lining. The ability to select from these approaches is hinged from knowing what is available in the market that will meet each owner's particular needs. Knowing what advantages and disadvantages that the trenchless technology offers will provide an advantage to reach the right decision when selecting the appropriate approach. This research provides information on the advantages and disadvantages trenchless provides in five (5) areas, environmental, safety, traffic, business and cost impacts.

Keywords: Safety, trenchless, underground utilities

1. Introduction

Every year municipalities, institutions, etc. see themselves with the need to upgrade, rehabilitate/repair or expand their infrastructure. The main portion of this infrastructure includes the utility systems that are composed or water, sanitary sewer, storm sewer and gas pipe lines. Millions of dollars are invested in these critical and necessary improvements or expansions to adequately provide these basic services to existing and new customers. The traditional approach to accomplish this endeavor continues to be primarily open excavation method.

In the last quarter century, new technological advances and approaches have been developed as alternate method to undertake the task of replacing, repairing, updating aging pipeline systems or installing new systems. (Trenchless Technology, Inc., 2017) This new approach implements equipment and methodology in the installation of piping system minimizing the need for open trench excavation. There are multiple systems utilized for the trenchless approach of construction such as slip lining existing pipelines, pipe bursting, micro-tunneling and horizontal directional drilling to name a few. As these systems have gained popularity and are increasingly being utilized as effective alternate, there is still a great majority of owners, engineers and contractors who continue with traditional open trench construction approach to execute their underground utility construction needs. (Trenchless Technology, Inc., 2017)

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1.1. Background

For several decades engineers, contractors and owners have employed the trenchless or no-dig method in the installation and rehabilitation of underground pipe system. With the latest technological advances, these methods are now posing some advantages to the traditional open cut methodology. The following are the trenchless technologies currently available:

- Horizontal Directional Drilling (HDD)
- Microtunneling
- Pipe Bursting
- Cured in Place Pipe Liners (CIPP)
- Sliplining

With these advances, other approaches have surfaced to supplement what was already established or as another alternative to these systems. Some of these advances and supplement technologies include:

1. CCTV line inspection to help with pre and post rehabilitation of pipelines to be rehabilitated.
2. Jetters: High pressure jetting systems with specialty nozzles to clean pipes in preparation of CIPP or Sliplining application. (A-1 Trenchless Services LLC, 2017)
3. Vactors: Vacuum excavators.

The primary technologies used in the approach of pipeline installation/rehabilitation identified above are employed depending on their applicability and nature of the project.

1.2. Purpose of This Study

With multiple methods now available for installing and repairing underground piping systems, the utility owners shall be better informed to implement the best approach at executing their utility repair or installation projects. This study is intended to provide key information in the advantages and disadvantages of each of these trenchless technologies as compared to the traditional open excavation approach.

The areas considered in this study to determine the advantages and disadvantages are as follows:

- Environmental impacts
- Safety
- Traffic impacts
- Disruption to businesses
- Cost evaluated in two parts: 1) direct cost for the actual design and construction of both alternatives and 2) indirect (social) cost impacts due to factors such as traffic, loss of business, and safety related issues.

1.3. Research Methodology

As utility owners take on a project to renovate or install a new underground system whether is a water distribution, sanitary sewer collection, gas distribution and electrical distribution system, many factors must be considered and the primary factor is cost along with impacts to their business. In order to identify the advantages and disadvantages of using trenchless technologies a case study approach was performed utilizing five (5) projects where different technologies were employed supplemented by research data obtained from two (2) papers published on related topics.

The following construction projects were analyzed in their use of trenchless technology:

1. Replacement of an Aging One Mile PCCP 36-inch Force Main to Minimize Environmental Impacts.
2. Improve Military Family Housing Infrastructure, PH 3, Misawa Air Base, Japan.
3. Upgrade Electrical Distribution System Phase 10, Misawa Air Base, Japan.
4. Reconstruct Taxiway Alpha 2 (Waste Water Drainage Line), Misawa Air Base, Japan.
5. Upgrade Hachinohe POL (Mabechi River), Misawa Air Base, Japan.

Projects no. 1, 3, 4 and 5 employed microtunelling for the installation of their underground utility. Project no. 2 used CIPP liner to rehabilitate existing sanitary sewer lines.

Key information also obtained from EPA's Collection Systems O&M Fact Sheet Trenchless Sewer Rehabilitation; and USDA/Forrest Service Decision Analysis Guide for Corrugated Metal Culvert Rehabilitation and Replacement Using Trenchless Technology.

2. Literature Review

2.1. Open Excavation Approach

Installation of a sanitary sewer main line or water main line will have a different impact installed in a rural area as compared to an urban area using the conventional method of open excavation approach. A rural area will not be as impacted as an urban area when it comes to vehicular traffic, however, the environmental impact may be a different story if the rural area encompasses factors such as wetlands, creeks and such. Further impacts, as compared to these two different locations rural vs. urban, include indirect cost created from fuel consumption, which impacts the public, and business loses due to public accessibility to stores and restaurants. Another factor, which impacts both areas is safety related to workers and if the site is not properly protected for the general public.

Cave-ins pose the greatest risk and are much more likely than other excavation related accidents to result in worker fatalities. Other potential hazards include falls, falling loads, hazardous atmospheres, and incidents involving mobile equipment. One cubic yard of soil can weigh as much as a car. "An unprotected trench is an early greave." (OSHA, 2017). The workers in the under-ground construction industry, especially water, sewer, and utility lines companies, have traditionally had a higher accident and injury rate than other workers in the heavy construction industry. (Arboleda & Abraham, 2004). Also, open trench at an intersection in a busy city can create significant negative traffic impacts, and restrict/reduce access to business.

The direct cost for open trench installation can greatly vary depending on factors encountered. For example, installation an underground utility line in a wetland area will pose a high environmental mitigation price to execute the project. Depth of the utility line can have a great cost impact with factors related to type of equipment, especially for deep installation, and safety where costly implementation of safety systems are mandated to protect workers.

2.2. Trenchless Approach:

Trenchless technology involves the installation, replacement or renewal of underground utilities with minimum excavation and surface disruption. Trenchless technologies have been used successfully for all underground utilities from, water, sewer, gas, and industrial pipelines to electrical conduit and fiber optics. (The International Society For Trenchless Technology, 2017) Trenchless Technologies are particularly attractive construction options in urbanized area with heavy vehicular and pedestrian traffic and numerous existing underground utilities. They are also attractive for crossing roadways, transportation corridors, and rivers and waterways. Trenchless also can be used to install, rehab or replace utilities located in environmentally sensitive areas and locations where surface access may be restricted due to the existence of structures or vegetation. (The International Society For Trenchless Technology, 2017)

In cases where multiple factors come into play for the rehabilitation of an existing pipeline, open trench may not be a practical option. For instance, replacement of a One Mile PCCP 36-inch Force Main in Fairfax County, VA. The original construction of the 36-inch Dogue Creek Force Main was in 1977 using open cut type construction technique which traverses wetlands, streams, residential properties and the Fort Belvoir Military Base. Due to permitting requirements, regulations, the development of the properties in the nearby areas, and the Fort Belvoir Military Base requirements, open cut construction was not a viable option for this force main replacement. Specifically, 84% of the force main needed to traverse the Fort Belvoir Military Base, and it was determined that open trench construction would be too disruptive to their daily operations. Additionally, the force main crossed a state highway which would also not allow open trench installation. As a result, alternative methods such as trenchless technologies needed to be considered for the installation of the new force main. (Notheis & Schillo, 2015)

The US Federal Government also takes into consideration the trenchless approach in the renovation and upgrade of some of their underground utilities for example the USDA and Forrest Service in their maintenance plan for underground corrugated storm drainage system.

Trenchless technologies reduce the need for open trenches which requires expensive trench protection thereby greatly reducing the risk for injuries from trench cave-ins and falls. Another safety risk that is greatly reduced with trenchless is traffic accidents as the area where the actual work is conducted is minimized and provides a more manageable site for traffic control. In the project mentioned above for the Replacement of a One Mile PCCP 36-inch

Force Main in Fairfax County, the best trenchless method decided was microtunneling and this approach consisted of six shafts ranging in depths from 9.75 m (32 ft.) to 15.85 m (52 ft.). (Notheis & Schillo, 2015)

There are clearly several advantages that trenchless construction presents over the traditional open trench approach. However, there are cases where there may not be an alternative to open trench and a more in-depth evaluation should be conducted.

A brief description of the five trenchless technologies identified in this study is as follows.

2.2.1. Horizontal Directional Drilling (HDD)

HDD is a steerable system for the installation of pipes, conduits and cables in a shallow arc using a surface launched drilling rig. Traditionally the term applies to large scale crossings in which a fluid-filled pilot bore is drilled using a fluid-driven motor at the end of a bend-sub, and is then enlarged by a washover pipe and back reamer to the size required for the product pipe. The required deviation during pilot boring is provided by the positioning of a bent sub. Tracking of the drill string is achieved by the use of a downhole survey tool (NASTT, 2017), as shown in Figure 1 below.

a

Figure. 1. (a) HDD Rig setup.
(Intermountain Drilling Supply, 2017)

b

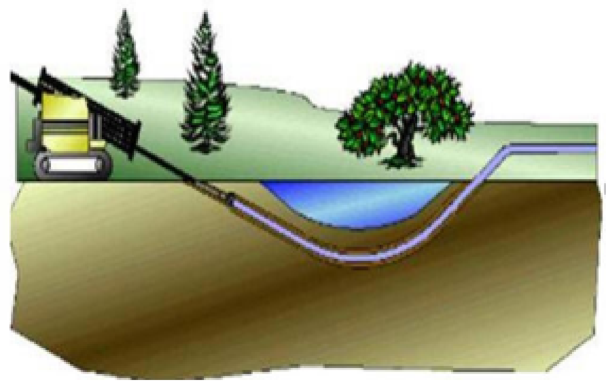

Figure 1. (b) HDD Process example.
(Underground Solutions, 2017)

2.2.2. Microtunneling

Microtunneling is a trenchless construction method for installing pipelines with the following attributes – remote control, guidance, pipe jacking, and continuous support, as shown in Figure 2.

Figure 2. Microtunneling launching pit with Equipment setup. (BRH-Garver Construction, L.P., 2017)

2.2.3. Pipe Bursting

Pipe Bursting is a replacement method - a technique for breaking the existing pipe by brittle fracture, using force from within, applied mechanically, the remains being forced into the surrounding ground (as shown in Figures 3 (a), (b) and (c)). At the same time a new pipe, of the same or larger diameter, is drawn in behind the bursting tool. The pipe bursting device may be based on an Impact Moling tool to exert diverted forward thrust to the radial bursting effect required, or by a hydraulic device inserted into the pipe and expanded to exert direct radial force. Generally a PVC or HDPE pipe is used. This method is also known as Pipe Cracking and Pipe Splitting. (NASTT, 2017)

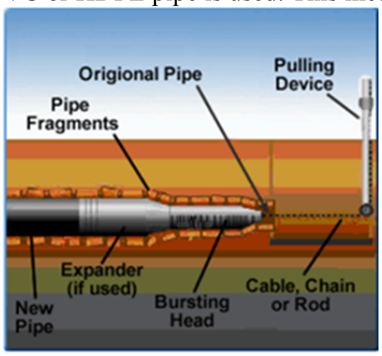

Figure 3 (a). Pipe bursting process. (TRIC Tools Inc., 2017)

Figure 3 (b). Pipe bursting operation. (A-1 Trenchless Services LLC, 2017)

Figure 3 (c). Pipe splitting operation. (A-1 Trenchless Services LLC, 2017)

2.2.4. Cured in Place Pipe Liners CIPP

CIPP is a lining system in which a thin flexible tube of polymer or glass fiber fabric is impregnated with thermoset resin and expanded by means of fluid pressure into position on the inner wall of a defective pipeline before curing the resin to harden the material. The uncured material may be installed by winch or inverted by water or air pressure, with or without the aid of a turning belt (Figure 4). (NASTT, 2017)

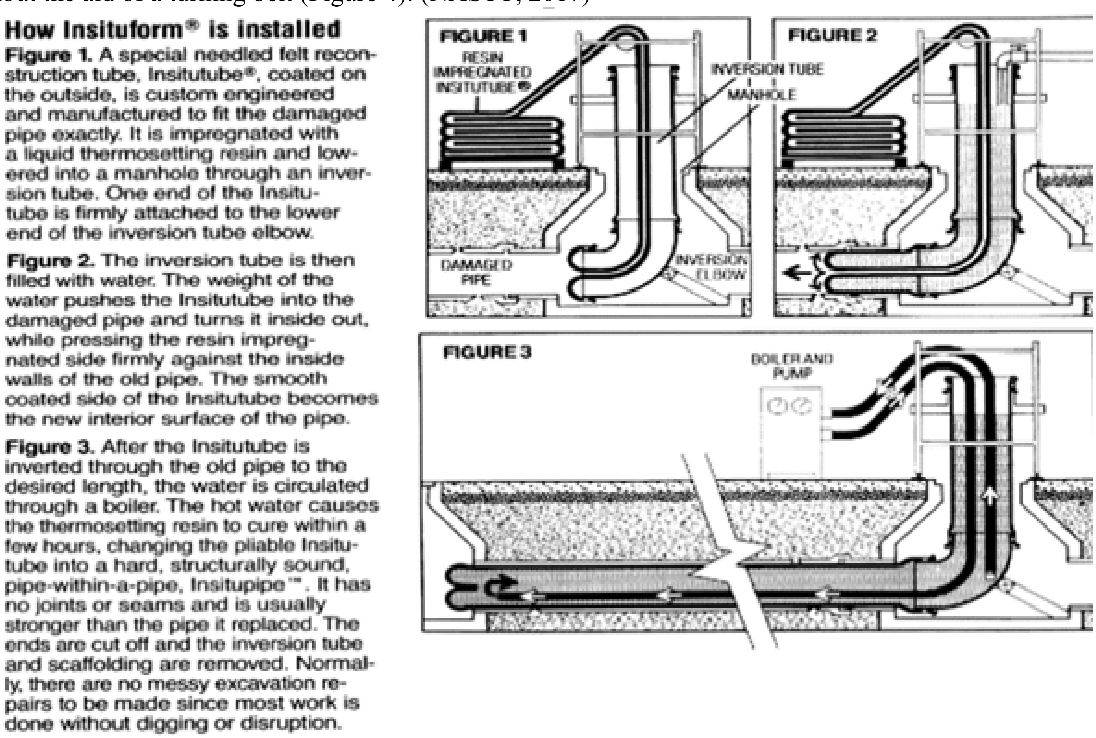

Figure 4. Typical Cure-In-Place Pipe (CIPP) Liner Installation, Source: Iseley and Najafi, 1995, (EPA, 1999)

2.2.5. Sliplining:

Sliplining (shown in Figure 5) is a general term used to describe methods of lining with continuous pipes and lining with discrete pipes. This method uses insertion of a new pipe by pulling or pushing it into the existing pipe and grouting the annular space. The pipe used may be continuous or a string of discrete pipes. (NASTT, 2017)

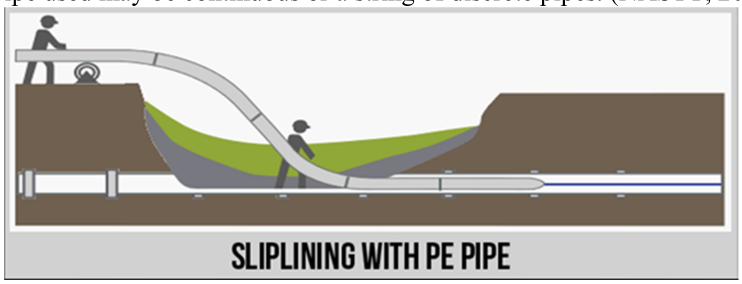

Figure 5. Typical sliplining process. (Trenchless Pipe Solutions, 2017)

3. Data Analysis

All trenchless technologies offer several advantages over the open excavation method of installation, replacement and repair of underground utilities. Some trenchless technologies, where some excavation is required as part of the system, i.e. directional drilling, microtunneling, sliplining, and pipe bursting, do not offer the full benefit of the advantages the no-excavation methods provide but greatly minimizes the implementation cost of environmental and safety control factors thereby also reducing the social cost impacts. The areas studied to establish the advantages and disadvantages of trenchless technology are discussed below and summarized in the subsequent table.

3.1. Environmental Impacts

The projects evaluated in this study presented a great advantage in the area of protection to environmental factors. It was observed that the primary area of concern for the Replacement of a One Mile PCCP 36-inch Force Main in Fairfax County, VA., was the environmental disruption that open cut would have involved taking that approach. The other benefit observed was greatly minimizing the magnitude of the Storm Water Pollution Prevention Plan and the effort that goes with the permit process, implementation and maintaining. For all project evaluated in this area, these advantages also applied for the portion where trenchless was implemented.

3.2. Safety Impacts

The area of safety was considered a substantial advantage using trenchless technology. The advantages were identified in the safety concerns that deep trenches pose such as cave-ins and fall protection. Although requirements are set by OSHA, USACE, etc., to abate potential safety problems by the installation of safety protection systems such as trench protection and fall arrest system, the absence of an excavation completely eliminates these factors. The other safety area where an advantage was observed is dealing with traffic safety and potential accidents from workers performing their duties alongside roads with active traffic as normally seen with trenching operations. The use of trenchless technology does not eliminate altogether the potential for accidents as each approach poses safety challenges in their particular implementation. The CIPP approach, that although does not require excavation, it does expose workers to traffic related safety issues and the placement of the equipment may be in the middle of the street where many times manholes are located. The others technologies such as microtunneling, HDD and pipe bursting require some excavation and many times placement of the launching equipment in the street bringing about the safety factors related to this approach.

3.3. Traffic Impacts

This area, overall, was considered an advantage based on the severity of the impact as compared to the open trench approach. As mentioned in the evaluation of safety impacts, all trenchless approach stand to impact traffic if positioning of the equipment is in the street. This is still considered an advantage because the impact to traffic is minimized due to the small foot print required. Where it becomes a great advantage is eliminating the need to cut

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across a heavily traffic street or highway. In the case of the projects in Misawa Air Base where two of these projects took place in an active airfield, obstructing taxiways and aprons was not allowed due to national security issues, microtunneling under taxiways became a big advantage.

3.4. Disruption to Businesses

As discussed in the literature review, open road construction in a heavy trafficked street within a business district can have a tremendous impact to businesses. Performing utility work in urban areas where there is a significant presence of businesses, trenchless technology is definitely an advantage from minimizing the disturbance and localizing construction operations to a small foot print. The businesses with the most impact are those located within the city's downtown area where open trench construction can sometimes extend beyond the schedule completion date and at times forcing small starting businesses to close their doors as a result of low sales.

3.5. Cost Impacts

Cost impacts are divided into two categories; first, direct costs, those associated with the design and construction of the project and second, indirect or social costs, those associated with the impacts attributed factors such as business losses, cost of fuel due to traffic delays and accident related costs. It is important to note that the social costs are extremely hard to quantify, thus this study does not attempt to estimate as it is not within the scope of this paper.

Figure 6 below shows a description of costs to consider in the typical approach of open trench as evaluated by G. Budhu and D.T. Iseley (1994).

Overall Cost	=	Direct Cost + Indirect Cost
Where:		
Direct Cost	=	Bidder Estimated Cost
Indirect Cost	=	Lane Closure Costs + Business Loss Costs + Fuel Consumption Loss Cost + Increased Pollution Costs + Increased Accident Costs
and		
Lane Closure Costs	=	Increased Travel Time x Average Wage x Average Daily Traffic x Construction Period for Closure
Business Loss Costs	=	(Income from Employee Reduction + Loss of Sales) x Construction Period
Fuel Consumption Costs	=	Based on Established Techniques as per Illustration
Pollution Costs	=	Based on Established Techniques
Accident Costs	=	(Number of Construction Accidents) x (Probability of the Occurrence of an Accident) x (Average Cost of Construction Accidents) + (Number of Traffic Accidents) x (Probability of the Occurrence of Accident) x (Average Cost of Traffic Accident).

Figure 6. Direct and Indirect Costs associated with Open Cut Method. (Budhu & Iseley, 1994)

3.5.1. Direct cost:

This data was obtained from the four (4) projects evaluated from the Misawa Resident Office in Misawa Air Base, Japan. The evaluation is primarily presented in general terms as a comparison of how the costs are distributed in the design and construction stages of the projects. The four (4) projects had between 15% - 30% increase in the design phase and this was expected since additional design effort was used to develop construction plans and specifications specifically for the trenchless portion of the construction documents. A comparison was performed for installation cost using open cut and installation of CIPP of the sanitary sewer system repairs and replacement under the "Improve Military Family Housing Infrastructure, PH 3, Misawa Air Base, Japan. The comparison revealed a considerable difference in savings with the CIPP trenchless approach. The cost, as compared with the open cut approach, was calculated as shown in Figure 7. Figure 8 below shows the distribution of the sanitary sewer mains with the traditional open cut approach and with trenchless technology (CIPP).

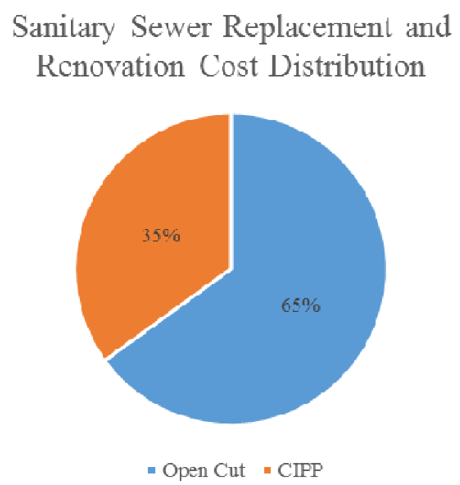

Figure 7. Cost distribution for open cut and CIPP method. (U. S. Army Corps of Engineers, Japan District, 2014)

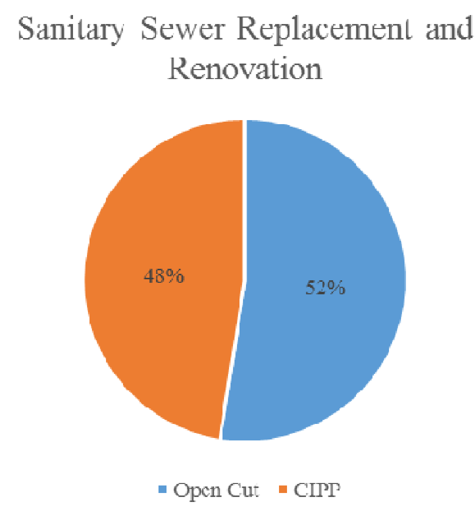

Figure 8. Distribution of sanitary sewer main installation by open cut and CIPP method. (U. S. Army Corps of Engineers, Japan District, 2014)

In this project, the CIPP approach proved to be a great advantage to the open cut method. Note that the CIPP approach was not implemented to the total amount of sanitary sewer lines in the project as some lines had factors to consider such as offsets beyond repairs and hydraulic improvements, i.e. change in slope, horizontal alignment and change in diameter.

3.5.2. Indirect/Social Costs:

These costs are extremely difficult to estimate but in comparison and taking into account the factors that are removed by using trenchless technology, qualifies this approach as an advantage in the installation/repairs of underground utilities. Note that the above factors evaluated in this study, all contribute to the social costs impacts and could be wrapped up into the social costs impact. However, the scope of this study is not to develop a formula or process to make a determination based on costs impacts but rather to provide the different approaches trenchless technology offers.

3.6. Advantages and Disadvantages by Technology

Table 1 summarizes the advantages and disadvantages that each trenchless technology in this study offers as they relate to the need of excavation to complete a project.

Table 1. Advantages and Disavantages of Trench Technology

Technology	Construction Application	Advantages	Disavantages
HDD: Horizontal Directional Drilling	Sanitary Sewer, Storm Drain, Casings	Long runs with no trench excavation	Excavation required for Lauching and Receiving Pits. Elevated cost for small jobs.
Microtunneling	Sanitary Sewer, Storm Drain, Casings	Long runs with no trench excavation	Excavation required for Lauching and Receiving Pits. Elevated cost for small jobs.
Pipe Bursting	Sanitary Sewer(Mainly). Utilities with plastic, clay pipe.	Long runs with no trench excavation	Excavation required for service lateral reconnection. Elevated cost for small jobs.
CIPP: Cured in Place Pipe Liners	Sanitary Sewer, Storm Drain.	Long runs with no excavation	Only applicable for rehab of existing pipelines.
Sliplining	Sanitary Sewer, Storm Drain	Long runs with no excavation	Excavation required for service lateral reconnection. Elevated cost for small jobs.

4. Conclusion

Trenchless technology offers many advantages for the installation, repairs, and maintenance of underground utility systems and with the correct approach, owners stand to see a substantial savings at their bottom line when projects are completed. The method to determine the suitability of the approach to meet the utility repairs or installation will require a technical and in-depth study.

This paper provides general, non-technical information to provide utility owners with alternatives, that current technologies make available to meet their needs or open new avenues, to traditional open trench excavation for underground utilities. Often there is no single solution and a methodical selection process as proposed here should never replace sound engineering judgment. The recommendations indicated here are meant as a guide to start the decision process by focusing attention to the relevant variables of the piping system that impact the performance characteristics of the system. An expansion of this method can incorporate many more elements of both the system characteristics and the method capabilities, as well as economic and social factors. A formal selection process should offer rational suggestions to help the decision maker. (McKim, 1997)

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Construction methods used for controlling temperature in mass concrete structures

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Abstract

The hydration of cement can release a substantial amount of heat that can be problematic in mass concrete structure. This heat of hydration (HH) can produce thermal stresses that can crack the concrete and compromise the integrity of the structure leading to its failure. Throughout the years, different methods have been developed in order to mitigate the negative effects of the HH on mass concrete structures. This study presents a comprehensive review of the previous methods documented in the literature that have been utilized in controlling the temperature rise due to the HH in mass concreting. The reviewed methods were divided into two main categories, namely supplementary material and construction methods. This paper focuses on the different methods of construction that are used to control the temperature rise in mass concrete structures. The paper also presents an analysis of these methods using findings from previous studies.

Keywords: Heat of hydration; mass concrete; cooling pipes, construction methods

1. Introduction

A common problem with the construction of mass concrete structures is the additional money, time, and efforts needed to deal with the heat of hydration (HH) released. The HH occurs as a result of the exothermic reaction between cement and water. This reaction causes a rise in the temperature inside the mass concrete structure, which creates a temperature gradient between the interior of the structure and its surface. Temperatures in the interior can reach up to 135°F depending on the size of the structure and the mass of concrete. The greater the mass of concrete, the higher the temperature will be. Most codes specify a temperature difference between the surface and the core of the concrete less than 35°F [1]. If this difference is surpassed, thermal cracking in the concrete may occur.

Thermal cracking is the result of the concrete surface and core expanding and contracting at different rates. The concrete expands as the temperature increases due to the release of the HH. However, the surface of the concrete structure cools faster than its core [2]. The heat in mass concrete escapes at a slower rate than is generated, which keeps the core hot and creates problems in the structure. Durability and strength are crucial in mass concrete structures, therefore the heat gradient that causes thermal cracking must be prevented and controlled. Proper placement of concrete and mix design are the best options when trying to reduce the heat released. For example, in normal concrete placement for isolated footings, the heat is dissipated into the soil without creating any temperature change in the structure. However, thermal cracking is extremely problematic in mass concrete structures, such as matt foundations, and can cause a lot of damage [2] .

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Mass concrete structures are structures with large concrete contents, such as dams, mat foundations, thick slabs, piers, and structural columns. It is defined by the American Concrete Institute as "any volume of concrete with dimensions large enough to require that measures be taken to cope with the generation of heat from hydration of the cement and attendant volume change to minimize cracking." The general rule is that any concrete element that has its smallest dimension 3 feet or more should be considered a mass concrete member. However, small concrete elements with high content of cement or cement Type III can be also considered mass concrete member due to the high amount of HH released [3]

2. Problem and objective

Several previous studies have investigated different methods for treating the effects of the HH. The body of knowledge in this area requires proper organization to facilitate the process of reviewing the literature for future researchers. As such, this paper aims at presenting organized summaries of previous studies conducted on different methods used for treating the HH in mass concreting. The main focus of this paper is the construction methods used for controlling the temperature in mass concreting as will be discussed in detail in the following sections.

3. Methodology

The methodology implemented in this research started with a comprehensive review and acquisition of all previous work and publications that discussed the methods used for treating the HH in mass concreting, particularly the construction methods. Then the focus was on the development of a classification system that categorizes previous work conducted on the treatment of the HH in a manner that reflect the nature of the work. Two categories were defined, as shown in Figure 1. The first one includes all the studies conducted on the treatment of the HH in mass concreting using construction methods. The second category includes the studies conducted on the effect of using different supplementary materials (SM) used in mass concreting to treat the HH, as shown in Fig, 1. The common research objective among the studies in the first category focuses on mitigating the negative effects of the HH by controlling the temperature of concrete. On the other hand, the studies of the second categories aimed at minimizing the amount of heat released during the hydration of cement through chemical reactions with supplementary materials.

4. Methods of reducing the heat of hydration

The construction method used for treating the HH in mass concrete structures is the main focus of this study. There are several construction methods that can be used to control the temperature inside the core of the concrete structure, such as: 1) precooling of concrete aggregates, 2) post-cooling of concrete, 3) insulation of the concrete member, and 4) pouring the concrete in thin lifts.

4.1. Precooling of Concrete

Precooling the concrete is the process of decreasing the temperatures of either the aggregates or the mixing water or both. This can be achieved using different methods, such as storing the aggregates in the shades and continuously sprinkling the coarse aggregates with water. Another method is using cold mixing water or replacing it with ice. Also, using liquid nitrogen (LN) either by injecting it in the mixing water or the fresh concrete is a frequent method for lowering the temperature of the concrete. Cooling the aggregates is more effective than lowering the temperature of the mixing water [3,4]. The rule of thumb is that decreasing the temperature of aggregates by 2°F can lower the temperature of concrete by 1°F. To achieve the same effect, the temperature of the mixing water should be decreased by 4°F. The maximum reduction in the temperature of concrete that can be obtained using cold mixing water and shaved ice are 20°F and 10°F respectively [3, 4]. Sometimes specifications limit the placement temperature of concrete to 50°F, which means a drop of 20°F or more in the concrete temperature is needed. In this case, shaved ice will not be effective; the alternative would be using LN. Injecting LN in the concrete can lower the temperature by 35°F [3].

The process of injecting Liquid Nitrogen (LN) into a cement mix starts by transporting it into a cement truck outfitted with a special tank capable of keeping the cryogenic temperature of the LN [5,6]. A truck must drive into a frame that will then be connected to a LN tank with an injection lance; the substance is then poured into the ready-mix trucks rotating drum via injection lance (which is a safe process). The truck then drives to the work site where it begins to pour the concrete mixed with LN, see Fig. 2.

A study by Nakane et al. [7] assessed the effect of LN, air-cooling of materials before mixing, and shaved ice as a replacement of mixing water on the strength and microstructure as well as the rate of hydration of cement in concrete. The study concluded that the different cooling methods considered do not affect the strength or the rate of hydration of cement pastes in concrete. The addition of LN has no negative effect on the compressive strength of the concrete but does not improve it either.

Other studies also investigated the effect of LN on concrete properties and the HH [5,6]. The study concluded that LN does not have a significant effect on the concrete hydration or most of its properties that are independent of temperature. However, it was noticed that concrete made with LN had the same slump as hot concrete, which is substantially lower than the slump of concrete made in room temperature. Also, it was concluded that LN extends the setting time of concrete. LN is much more effective at cooling concrete than regular ice is due to its extremely low temperature of -196°C; also, it is readily available and inexpensive. However, there are disadvantages for the use of LN in concrete as well. One common concern is workers' safety, since prolonged exposure to liquid nitrogen can lead to burns and frostbite. It can also damage the rotating drum of the truck mixer because the LN makes the steel become more brittle and more prone to crack. Another concern is that LN can negatively affect the proper development of compressive strength of concrete because of the localized freezing that prevents the complete hydration of the cement.

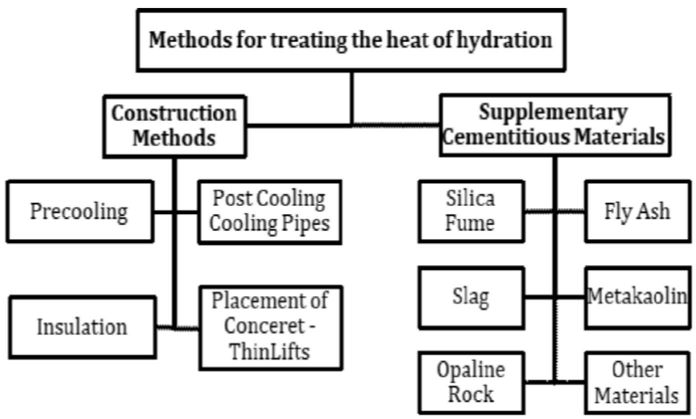

Fig. 1. Classification of different methods used for treating the HH

An article presented a case study on the successful use of LN to cool concrete in the Turnpike project in central Texas [8]. Although the article does not report any scientific experimentations, it highlights some valuable field experiences for mixing concrete with LN. For instance, mixing concrete with LN was done on site by inserting a 6-ft lance connected to a LN tank in a concrete truck while the batching the concrete. The article refers to the advantages of using LN for cooling concrete over chilled water or crushed ice regarding the inconsistency in the slump obtained when using the latter methods. The article also argues that LN can be the most economic choice since it is less labor intensive compared to crushed ice, and due to the high costs of water chillers and fuel needed for cooling. The article also refers to the previous disadvantages mentioned above [5,6,8], and to the importance of conducting further experimentation to assess the effect of LN on different concrete properties.

4.2. Post-Cooling of Concrete

The cooling pipes method, typically referred to as post-cooling, has been one of the most common methods for controlling the temperature in mass concrete structures. In this method, cool water is circulated through small diameter pipes embedded in the body of the concrete structure, as shown in Fig.3. The use of cooling pipes is very popular in dam construction. Several thermal studies have been conducted to evaluate the effectiveness and drawbacks of the use of cooling pipes in mass concreting. The determination of the size of the pipes, spacing between pipes, rate of flow, and temperature of the cooling water can be a sophisticated task. This is due to the fact that there are several factors that affect the HH in a mass concrete structure that should be taken in consideration when designing the cooling pipe system. Some of these factors are: type of cement, supplementary material, temperature of mixing water, formwork, lift thickness and rate of placement, and climatic conditions [9]. Other factors that pertain to the design are, the type of pipes used, rate of flow of water, and the temperature difference between the cooling water and concrete. Usually the pipes are equipped with control valves to control the rate of flow. Also, special attention should be given to the outlet water as the discharge temperature can be high enough to compromise the safety of workers. The source of cooling water is usually public drinking supply; however, in remote areas, water trucks and onsite chillers can be used to supply and cool the water [10] (Roush & O'Leary 2005).

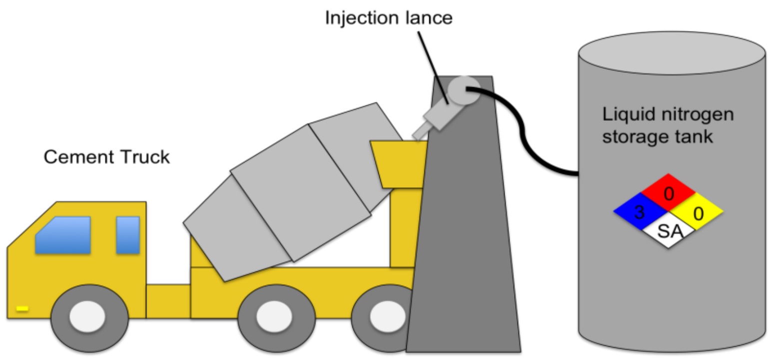

Fig. 2. Process of injecting concrete with LN using a lance connected to a LN tank. [5]

Another important factor that may affect the efficiency of the cooling pipe system in controlling the temperature of the mass concrete structure is the type of material of the pipe. Most large mass concrete structures rely on metal pipes to cool the internal temperature due to its high thermal conductivity. A study conducted by Zhu [11] illustrated the calculations formulas needed to replace metal pipe systems with nonmetal ones. The study presented different formulas for computing the radius of pipes, horizontal spacing between pipes, and the time required to decrease the temperature to a specified degree for different types of pipes. The study concluded that polythene pipes could be very convenient in the construction of mass concrete structures.

Cooling coils have been used as well to control the internal temperature of mass concrete structures. Although very costly, some have been used in larger structures such as dams as well as tunnel plugs. The concept of those cooling coils is similar to the pipes since they are also embedded in the structure. The use of a refrigeration system has also been explored with these coils. They are used to distribute ammonia liquid within a system to make ice and chilled water. The size of a structure really depends on the refrigeration system that is put in place; a dam, for example, it would require a large refrigeration system to control the internal temperature and cycle the ammonium fluid [12]. These systems would also be able to produce ice or chilled water for the desired effects [13].

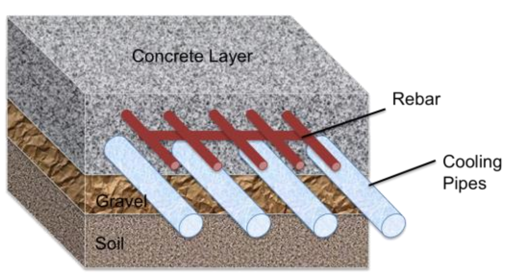

Fig. 3. A cross section of the interior of a concrete slab with cooling pipes [2,11]

While very few studies addressed new innovations in the cooling pipe systems used, most studies covered in the literature focused on the thermal analysis of cooling pipes. One of the most notable study is the U.S. Army Corps of Engineers technical note on the thermal studies of mass concrete structure [14]. The note classified mass concrete structures into 3 types: 1) gravity structures, such as dams and lock walls, 2) thick shell structure, such as arch dam, and 3) thick reinforced structures, such as locks, pumping stations, massive foundations, and bridge piers. In this report, thermal analysis studies were classified into three categories according to their complexity.

The first level (L1) represents the simplest of form of thermal analysis. This level requires basic analysis based on generic assumptions. This type of analysis is suitable when the consequences of thermal cracking are insignificant, and do not affect the safety or stability of the structure. This level of analysis is appropriate at the feasibility stage and is usually used to determine control and structural joints spacing as well as the thickness of lifts. Thermal analysis at L1 can be used for diversion structure for irrigation canals, thick reinforced foundation, and massive bridge piers.

The second level (L2) requires more solid and detailed analysis of the thermal stresses in the structure using a variety of tools. This level of analysis should be conducted when thermal stresses are significant enough to be of a concern to the structure safety and stability. The analysis should be used with structures such as, gravity dams, tunnel plugs, low-head arch dam, and pumping stations.

The third level (L3) incorporates the most sophisticated level of analysis and is needed for critical structures where cracking creates major risks to the structure. The methods of analysis at this level can be very costly and time consuming. They are required for complex and new structure when little information and no prior experience are available. The L3 analysis is useful in when interaction between several stresses exists from different loading conditions. This type of analysis can be applied to gravity and some arch dams [14].

A thermal analysis study was conducted using 3D finite element analysis of a pipe cooling system embedded in a spread concrete footing. The pipe was modeled using a line element, and the internal flow theory was used for estimating the changes in the temperature of the cooling water. The footing was cooled with a pipe loop embedded in the concrete with both an inlet and outlet. The outlet values represent the heat that is being dissipated over a 10-day period while the inlet represents the lower values of the cooling water, which is responsible for moving the heat through the outlet. The results were verified to actual data from the bridge site [15].

Another thermal analysis study focused on the mass concreting in dam construction. The study considered the general laws of heat transfer (radiation, convection, and conduction) as well as the climatic factors that can affect the temperature of the concrete, such as solar radiation, and air and water temperature. Other factors that affect the HH during the construction phase are: type of formwork, time to remove formworks, and rate and thickness of lift placement. In this study, a program was developed to simulate the construction phase of the dam. A case study of Alqueva's dam was presented; the HH of the dam was estimated, and calculation of the construction phase was done [9].

One thermal analysis study was conducted on double-layer staggered heterogenous cooling pipes embedded in a concrete slab. The analysis was conducted using 3-D finite analysis and the equivalent equation for heat conduction. The mathematical model aimed at stimulating the temperature variations of mass concrete structure. The cement HH was modeled using a double exponential function, while the temperature of the outlet water was estimated using the law of conservation of energy. The results were validated using a case study of an arch dam in China that was under construction at that time [16].

Although cooling pipes are effective in controlling the temperature in mass concrete, thermal stresses can still occur inside the body of the concrete especially near the pipes. A study was conducted to simulate the propagation of thermal analysis based on particle flow code. The 2D particle flow represents aggregates and mortar using particles of different sizes and simulate the cement paste using parallel bonds. The 2D particle flow was used to model a concrete slab that has a length of 1 meter and width of 0.5 m. The study concluded that thermal cracks might occur if the temperature of the cooling water is too low or the temperature gradient between the concrete and the cooling pipes is high. Bond breakages was observed where thermal cracks occurred [17].

One study presented a new method for controlling the concrete temperature during the construction of a large project in China. The method is based on controlling the circulation of water between a foundation slab and a mass concrete structure. The design consists of a dewatering well that travels to the natural ground and flows to a thermostat tank. It then leads to a cooling pool that is located over a foundation slab above the surface, which moves back to the natural ground and into the drainage ditch. The idea is to develop a self-sustained concrete water-cooling system using water from the dewatering process. The average temperature of a concrete slab is around 32°C, but the study showed that the water reduced the temperature to almost 24°C in a 24-hour duration of circulation. A finite element analysis of the foundation was conducted with and without the circulating water. The results were verified using actual measures from the site [18].

A major drawback that the cooling pipes have on these mass concrete structures is that, they can produce a tensile stress brought on by a sharp cooling when water is run through the pipe [19]. Should there be a massive temperature change between the surface of the pipes and the interior of the concrete, cracking will occur. At this point of cooling the creep is low while the elastic modulus is high, thus resulting in cracking from the inside. Temperature control is an expected factor to prevent this.

4.3. Insulation

Insulation is another method that has been used for reducing thermal cracking. The surface of the concrete is insulated to decrease the rate of cooling, see Fig. 4; hence, minimize temperature gradient between the surface and core of concrete [4]. It is important to note that thermal cracking is caused by the large temperature difference between the interior and surface of the mass concrete structure. As concrete cools, it starts to shrink. The resulting temperature from heat of hydration can exceed the temperature of the immediate environment. Insulation assists in maintaining the same shrinkage rate for the surface and the core of concrete, which prevents thermal cracking. Insulation is inexpensive, but must be in place for a long time. This can lead to prolonged construction durations, which cost additional money. The materials used for insulation can come in many forms, but it all depends on how much the temperature needs to be reduced [2, 20].

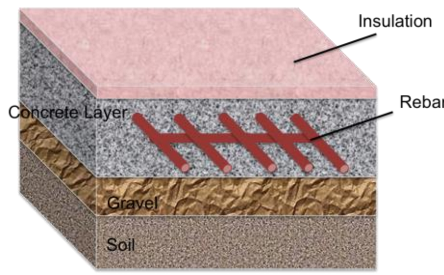

Fig. 4. Insulation of a mass concrete member

5. Findings

The review of the literature shows that there are very few construction methods that can be used for controlling the temperature in mass concreting. However, there are still some concerns about the efficiency and the potential risks that these methods have on concrete. For instance, the utilization of cooling pipes might lead to thermal cracking at the locations where the pipes are embedded if the temperature of the cooling water is not appropriately controlled. Some concerns are also raised regarding the impact of LN on the drums of the concrete truck mixers; and insulation requires very long time, which might render it expensive. The literature did not include any comparative analysis, financial feasibility evaluation, life cycle assessment, or life cycle cost analysis of the methods addressed above. A rough analysis would reveal that LN can be the best choice among the available construction methods due to its effectiveness at cooling the concrete, and cheap price. LN does not require any effort or special preparation except for the special lining of the drum of the concrete mixer; it only needs to get injected into the mix before pouring. Although cooling pipes are good for large structures, they are expensive when compared to liquid nitrogen, and requires continuous monitoring of the cooling water temperature and rate of flow. The advantages and disadvantages of the construction methods that were explored are shown in Table 1.

Table 1: Comparison of construction methods used for controlling temperature in mass concreting

Construction Methods	Advantages	Disadvantages
Cooling Pipes	• Effective for large structures (dams)	• Expensive • Might lead to thermal cracking around the pipes
Liquid Nitrogen	• Effective at cooling • Readily available • Cheap	• Concrete strength may not develop properly due to localized freezing • Needs special lining for the concrete mixer
Insulation	• Inexpensive	• Not as effective as other methods • Requires longer durations

6. Conclusion

This paper presented a thorough review of the different construction methods used to control temperature in mass concrete structures. The paper presented concise summaries of previous studies and publication that focused on the construction methods used for controlling the HH. The majority of the studies conducted focused on thermal analysis of cooling pipes of different arrangement, materials, flow rates, and cooling water temperatures. The review shows that liquid nitrogen is a cheap and effective way of reducing the HH. While cooling pipes can be very effective in dam construction, it is very costly and there are concerns about the posing risks to the integrity of the structure. Most error associated with these methods can be avoided by having experienced engineers and personnel to monitor the progress of the concrete structure. In addition, some method works best for certain locations, because climate does play a role in curing of cement. Some areas that are colder would benefit more by using the insulation method, and locations with warmer climate should use the cooling pipe method and Liquid Nitrogen injection method. The paper should prove useful in providing a recent review for the current construction methods used in controlling temperature and treatment of HH in mass concrete structures.

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Construction 4.0: Towards Delivering of Sustainable Houses in South Africa

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Abstract

Housing is a major challenge for most African countries including South Africa which is characterized by numerous backlog of housing provision. This study seeks the adoption of construction 4.0 principles for reducing the housing backlog experienced within the country. Therefore, the study examines the impact of applying construction 4.0 for delivering sustainable and quality accommodation and evaluates the hindrance in its adoption. Construction 4.0 involves the application of industry 4.0 concepts a synonym for the 4th industrial revolution that originated from the German manufacturing sector to the South Africa housing industry with the intention of creating a digital industry using a sophisticated gadget like drones, RFID, laser scanning, 3D printing and many others. Convenience sampling method was used in obtaining data from practicing construction professional in Johannesburg Gauteng province South African. A total of 184 questionnaires were obtained from the construction professionals out of 220 that was distributed. The data were analyzed with SPSS V 24, using, mean score, regression and factor analysis. The study discovered that there is a positive impact on the use of construction 4.0 principle for housing delivery as it reduced cost and time overrun thereby ensuring the prompt delivery of affordable and quality houses. The foremost hindrance to the adoption of construction 4.0 principle is the cost of investing in modern technology by small construction firms. The study contributes to the innovative ideas for housing delivery in South African it recommends that strategies and infrastructures should be put in place towards enabling the digitization of the construction industry and increase the awareness of construction 4.0 among construction professionals.

Keywords: Construction 4.0; Digitalization; Industry 4.0; Sustainable Housing.

1.0 Introduction

Housing is often described as the physical space in which human being occupy, carry out their daily activities and express a form of possession over. Delivering quality and sustainable houses to meet the required supply in view of the growing population is a global problem challenging both in developed and developing countries including South Africa [1], [2]. Khumalo [3] posited that South Africa as adopted housing delivery strategy in meeting the demand for housing such as the establishment of RDP houses, social housing and informal settlement directed at the low and middle-income earners.

One of the effective strategy employed by the government was the creation of RDP houses established in 1994 with the goal of reducing housing shortage but the Government faced challenges as regarding the quality with most houses regarded as sub-standard [4]. In the same vein, Dzunisani [5] opined that the present public houses are not sustainable with most of them serving as a home for a crime with dilapidated building finishes. Burgoyne [6] reported

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that lack of stringent project management was some of the factors responsible for substandard work as theft of the building supplies were always occurring on the site thereby making the contractors use any available materials on site

However, creation of sustainable and quality housing has been the vision of the government of South Africa as stipulated in the national housing code. Towards meeting the requirement of the national housing code South Africa Government as adopted several ways such as; public-private partnership, concession, and improvement on the traditional methods of housing delivering [7], [8]. Dave et al. [9] avowed that some of these methods as not function effectively because the profitability of public housing projects is low thereby leading to delay and uncertainty. The digitalization of the construction industry can offer greater opportunity regarding the elimination of delay for affordable and quality housing provision and hence is emerging as an alternative method to housing delivery strategy. Although the digitalization of the construction industry was emancipated from the fourth industrial revolution referred to as industry 4.0.

Industry 4.0 has its origin in the Germany manufacturing sector using smart technologies coupled with the internet of things/services thereby facilitating easy integration of different technologies like; cloud data, robotics, and virtualization for manufacturing that enables the connectivity of people with machines [10], [11]. Montgomery [12], Buss and White [13] and Osunsanmi et al. [14] applied the concept of industry 4.0 to the construction industry and called it construction 4.0 which aims at digitalizing the construction industry through adopting technologies powered by industry 4.0 such as RFID, 3D printing among others.

In industrialised nations like the United Kingdom, America and Germany and other European countries studies such as [12], [15], [16] have established the benefit of applying construction 4.0 in providing sustainable and affordable houses. But in many Africa countries, including South Africa such studies are still at its infancy stage. Thus, this piqued the researcher into evaluating the impact of Construction 4.0 on delivering quality and sustainable houses.

2.0 Review of Literature on Housing and Construction 4.0

2.1 Housing in South Africa

Ukwayi et al. [17] and Aigbavboa [18], reported that the concept of housing has its origin in the paleolithic period when the early man started using natural materials like stone, wood and animal skin to form a shelter for themselves. This opinion recognizes housing as the creation of mere shelter serving as a protection from external aggression and other climatic factors such as rain, sun, and other extreme weather conditions. Authors such as; Bonnefroy [19], Abullahi and Aluko [20], Aluko [21] and Ajayi et al. [22] opined that housing is a combination of the dwelling, the home, the immediate environment and the community. This implies that housing is not simply the residential unit or even the piece of real estate where it is located, but is instead the collective housing units, associated land uses, and social environment that composes a neighborhood.

South Africa recognized the benefit of housing thereby proposing three major forms of housing delivery strategies existing which are; public housing, self-aided help and market enabling [18]. According to Keivani and Werna [23] public housing delivery strategy was established to provide affordable, sustainable housing for low-income families at a reduced cost. In South Africa the public housing policy is stated as the reconstruction and development programme housing (RDP) the policy was developed to end the apartheid regime in 1994 to curb the inequality in getting the access to the housing [24], [4]. Harris and Giles [25] reported that the public housing policy has its advantage, but it is faced with challenges of meeting the high demand rate, poor maintenance, lack of skills and theft on construction sites. This implies public housing delivery strategy as a good principle but a poor implementing strategy.

Self-aided help housing delivery was coined by Jacob Crane in 1948 due to the limitations of public housing provision [26]. Chetty [27] submitted that this concept is based on the notion that Government may assist the individuals in developing their house. Adebayo [1] revealed that the self-aided housing delivery strategy was practiced in South Africa prior to the world war 1 were service land was initially developed at Pimville in existing Soweto. Just like every other government housing delivery strategy in South Africa the self-aid policy also experienced some changes after the apartheid period. The period before apartheid was characteristic with inequalities and inefficiencies as some of the lands were encroached upon thereby making the Government convert them to controlled site and service camps. Landman and Napier [28] discovered that the post-apartheid period witnesses the self-aided help transformed to people housing process (PHP) where the Government provides the land for development, urban services, knowledge development and an option to construct the house step by step. Critics such as; Chetty [27], Fish [29] Moore [30] opined that the self-aid form of housing delivery has its own disadvantage in the sense that if not properly managed it will lead to slums as some owners erect substandard and less adequate houses. This suggests that self-housing policy cannot be determined as a self-sufficient form of housing delivery strategy.

The housing delivery strategy through enabling the markets is focused on making the housing provision more efficient through assisting the building industry [18]. Harris and Giles [25] submitted that this method works through the provision of better building materials, training of construction tradesmen and entrepreneurs. Nubi and Omirin [31] also shared a similar opinion and submitted that the housing sector can be improved when the market is enhanced with the improvement of the mortgage sector. This method is good for providing housing but if not carefully implemented it could exempt the poor who are the biggest demand for housing in developing countries. Ajayi [32] also supported this assertion by submitting that this housing delivery strategy may leave the poor completely depending on the success or failure of the free market.

It can be inferred from the reviewed literatures on housing delivery strategies a paradigm shift is needed in the delivery of housing. In support of this opinion Adebayo [1] recommended that South Africa needs to establish a modern housing delivery strategy because the physical and political segregation during the apartheid period as made it difficult for past strategies to effectively meet demand for housing during post-apartheid periods. Although the past apartheid government alone cannot be blamed alone for the causes of housing shortage within the country. This study opined that the old ways of housing delivery should be supported with modern innovations such as the fourth industrial revolutions.

2.2 Application of Industry 4.0 to the Construction Industry (Construction 4.0)

Industry 4.0 was coined from the fourth industrial revolution that was created by the German Federal Government in respect of its manufacturing sector. Montgomery [12] submitted that prior to the fourth industrial revolution the manufacturing sector has witnessed three past revolutions namely; mechanization, electrification, and digitalization. Schwab [33] avowed that the present revolution (industry 4.0) provides the opportunity to fully integrate people and digitally controlled machines with the assistant of the internet and information technology. Also, Lu [11] affirmed that the advent of industry 4.0 provided the connection of people and objects towards creating the factory of the future that ensures the full digitalization of the manufacturing sector. This suggests that industry 4.0 encompasses the diversity of technologies that assist in the advancement of a digital and automated manufacturing environment.

Lu [11] opined that the fourth industrial age is unique because of its effortless application into different disciplines and industries. But is development has been remarkable in the manufacturing industries as confirmed by [34]- [36] when they reported that the fourth industrial revolution provided the opportunity for additive manufacturing or 3D printing that ensures the creation of a physical object from a 3D model or drawing. However, Schwab [33] submitted that researchers are already working on the creation of 4D printing to manufacture materials that can respond to their environment it is perceived that at this stage it will be possible to print cloths, footwear, furniture and many others. It can be inferred that the use of industry 4.0 in the manufacturing sector is limitless.

Apart from the manufacturing sector, reviews from literature as shown that the industry 4.0 has created a change of activities in different sectors. Manohar [37] and Schreilber [38] reported that in the automotive sector industry 4.0 has made it possible for the car to be perceived as a computer on wheels with 40% of the car controlled by electronics. The finance industry in some developed countries such as Saudi Arabia, Honduras, Isle of man and among others has experienced the benefit of the industry 4.0 through the adoption of blockchain (a centralized ledger powered by the fourth industrial revolution) to reduce transaction cost and eliminate middlemen through creating a cryptographically secured trusted ledger connected by computers that verify a transaction before it is recorded [33]. The healthcare sector also gained from the industry 4.0 through the sequencing of genes and development of new diagnostical methods [39].

Although the construction industry has not fully harnessed the benefits of the industry 4.0 concepts especially in the developed nations [40] and [41]. Recently Osunsanmi et al. [14] related the industry 4.0 concepts to the construction industry and referred it has construction 4.0. The authors provided a framework for the application of industry 4.0 for the construction industry in a developing nation using South Africa as a case study.

The authors perceived construction 4.0 is achieved from the combination of a smart construction site, simulation, and virtualization which can ensure construction project performance. The smart factory will be created by applying industry 4.0 innovations such as internet of things, RFID (Radio-frequency identification) and many others. The simulation stage will include the use of BIM (Building Information Model), virtual reality and 3D printing to design and manage construction project whereas the last stage cloud computing will be used to store data and thus enhance

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free flow of information within the industry as it is expected to deliver fast information for the construction professionals using cloud data storage.

But the framework provided by Osunsanmi et al. [14] concentrated more on improving the construction industry while neglecting the housing delivery strategies. This study draws from construction 4.0 concepts towards creating a framework for incorporating ensuring quality and sustainable housing.

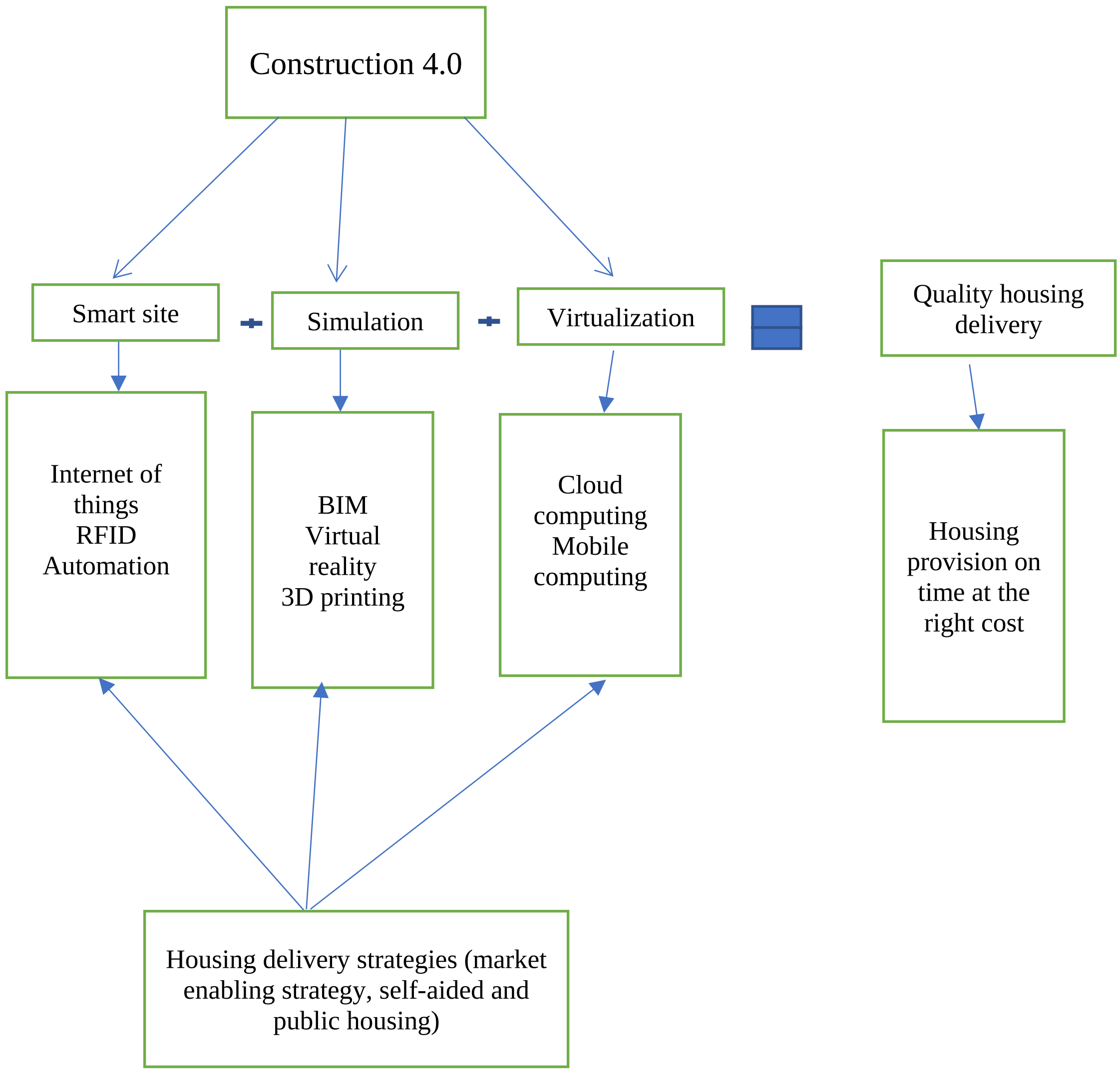

Figure 1; Conceptual framework
Source; Adapted from Aigbavboa [18], Mahamood and Akinlabi [36], Osunsanmi et al. [14]

The framework is formed based on the notion that sustainable and quality housing will be achieved by a combination of all the different housing delivery strategy to provide a decent housing after recognizing that a single housing delivery strategy cannot meet the housing need of a nation [24], [18], [22]. The framework showed that the housing delivery strategies should be supported by construction 4.0 concepts. For instance, the BIM and other simulation tools could be used to simulate the houses intend to deliver through site and delivery schemes in other to control the houses developed through the scheme. Sikota [2] submitted that during the construction of RDP buildings theft of building materials usually occur on site. Whereas RFID has been suggested by [42]- [44] for controlling security on construction sites. A combination of the technologies powered by construction 4.0 with the housing delivery strategies will assist in delivering quality and available houses in the country.

3.0 Methodology

The rate of development of some countries is usually measured by quality and sustainability of its housing delivery strategies [6]. This study proposes the adoption of construction 4.0 principles for improving the quality and sustainability of housing provisions. Construction 4.0 which is a termed coined for the digitalization of the construction industry on the background of industry 4.0 has been shown by; Li and Yang [41], Osunsanmi et al. [14] for increasing the performance of the construction industry and thus improve the delivery of housing. The quality and sustainability of the houses are measured in relation to the time and cost overrun for delivering the houses.

A convenience sampling technique that is a non-probabilistic sampling method was adopted for this study. The study used a close-ended questionnaire for data collection directed to practicing construction professionals and housing officials within the Gauteng province in Johannesburg South Africa. The questions posed by the questionnaire was acquired from reviewing different articles and journals related to construction 4.0, industry 4.0 and the South African construction industry.

A total of 184 questionnaires were obtained from the respondents out of 220 that was distributed and ensuring that the respondents have been involved in one or two projects where the application of a new technology such as BIM was used. The questionnaire was analyzed using SPSS version 24 while adopting statistical tools such as regression analysis, mean item score, and factor analysis. The mean item score were used to appraise the respondent's readiness to use construction 4.0 principles for housing delivery, regression analysis was used to determine the impact of construction 4.0 principles on providing quality and sustainable housing regarding time and cost performance while the factor analysis was used to explore the factors hindering the adoption of construction 4.0 for housing delivery.

4.0 Discussion of Findings

This section presents the result and findings along with the discussion of findings from the returned questionnaires that were distributed to the construction professionals.

4.1 Readiness to Adopt Construction 4.0

The respondents were asked to rate their readiness for applying construction 4.0 principles in conjunction with housing delivery strategies. Variables for measuring construction 4.0 principles was sourced from Osunsanmi et al.[14] and the authors divided the principles into smart construction site, simulation, and virtualization tools and are further broken down into various components and presented to the construction professionals to rate their level of readiness towards adopting them with their response provided by Table 1. Scanning through the table it can be deduced that the respondents are willing to adopt the construction 4.0 principles judging from all the mean score attributed to the variables. This outcome coincides with the opinion of [13]- [14] when they confirmed that that construction professionals and housing experts are willing to adopt modern technologies for their daily activities but are limited due to their low awareness of the modern innovations.

For the construction 4.0 concepts that support the establishment of a smart construction site, table 2 showed that the respondents are very ready to adopt prefabrication/modularization and the use of radio frequency identification (RFID) for construction activities during the delivery of houses. Their readiness to use prefabrication and RFID can be related to the already established benefit of adopting prefabrication in other developed countries as shown by authors such as [45], [46]. Likewise, the use of RFID has been prescribed by authors such as Sardroud [43], Costin and Telzer [44] they discover that it allows the automation of construction process by allowing effective tracking of equipment and tools, theft prevention and inventory management. Other factors the respondents are ready to adopt in order of hierarchy are; automation, product lifecycle management, robotics, additive manufacturing, internet of things, internet of services and human-computer interaction

Table 1. Readiness to adopt construction 4.0 principles

	Mean	Rank
Smart Construction Site		
Prefabrication/ Modularization	4.82	1
Radio-frequency identification (RFID)	4.75	2
Automation	4.53	3
Product life cycle management (PLM)	4.32	4
Robotics	4.21	5
Addictive manufacturing	4.00	6
Internet of things	3.55	7
Internet of services	3.27	8
Human-computer interaction (HCI)	2.64	9
Simulation tools		
Building information modeling (BIM)	4.93	1
Augmented /virtual/mixed reality	4.71	2
Virtualization		
Mobile computing	4.62	1
Cloud computing	4.51	2
Social media	4.32	3
Big data	4.00	4

Table 1 showed that the construction professionals are ready to adopt of Building information modeling as a form of simulation tool followed by Virtual reality. Regarding the use of virtualization, the table showed mobile computing with a mean score of 4.62 is the factor the respondents are ready to adopt the most. Followed by; cloud computing, social media, and big data. The findings from this study revealed that the respondents are ready to adopt construction 4.0 principles that they are familiar with and have been used extensively in other countries such as RFID, BIM, mobile computing, and prefabrication.

4.2 Hinderance to the Adoption of Construction 4.0

This study adopted principal component analysis also called factor analysis to determine the hindrance to the adoption of construction 4.0 principles. Table 2 presents the KMO and Bartlett's test which shows that at a chi-square value of 359.620 at 136 degrees of freedom, significant at 5% confidence level. This, therefore, suggests correlation among the chosen factors (hindrance to the adoption of construction 4.0) and supportive criterion for factorability.

Table 2. KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.766
Bartlett's Test of Sphericity:		
	Approx. Chi-square	359.620
	Degree of freedom	136
	Significant level	0.000

The study adopted varimax rotation method, which shows the seventeen (17) factors loaded differently on 3 components which hinder the adoption of construction 4.0 as reported in Table 2

Table 2. Rotated component matrix

	Component		
	1	2	3
Complex nature of construction project	.868		
Site based nature of the construction industry	.856		
Construction workers resistance to change	.817		
Lack of standard and policies	.739		
Uncertainty of construction project	.663		
Low technical know how		.845	
Construction firm low investment to research		.821	
It reduces the capability of improving employing potentials		.760	
Higher requirement for computing equipment's		.744	
Difficulty in explaining the output from the new technology to the client		.690	
Low investment in research on behalf of the construction firm		.673	
Difficulties in setting performance standards for employees		.654	
Difficulty in creating regulations and procedures to guide employees in adopting modern technologies		.585	
High cost of maintaining the technology			.841
Cost for periodic training/seminar for employees			.821
High Cost of educating the construction site workers on the usage of such technologies			.759
High cost for data security and data protection			.412

The items that have the highest coefficient in all the three components are usually considered. On the first component, 'complex nature of construction project' and 'site-based nature of the construction industry' are the items with the highest component. Regarding the second component 'low technical know how' and 'construction firm low investment for research' are the highest loading factors. While 'high cost of maintaining the technology' and 'cost for periodic training for employees' were highly loaded in the third component.

The name given to the components is usually adopted from the highest item within each component therefore, the three components obtained in the analysis are named thus; 1) nature of the construction industry, 2) poor technical know how, 3) high cost. These are the three hinderance to the adoption of construction 4.0 for housing developments within South Africa.

4.4 Impact of Construction 4.0 on Housing Delivery

This study adopted regression analysis to examine the impact of construction 4.0 principles on housing delivery in South Africa. The housing delivery was measured in terms of cost and time overrun for delivering houses when using technologies supported by construction 4.0 concepts such as BIM and RFID. The cost and time overrun was used as the dependent variable while the use of construction 4.0 principles served as the independent variable. The outcomes are presented in table 3 and 4.

Table 3. Regression Analysis of effect of the use of construction 4.0 on cost overrun for housing delivery

	B	Std. Error	t	p value	Remark
(Constant)	22.471	82.824	0.021	0.008	Sig.
Use of construction 4.0 principles	1.774	19.908	0.129	0.000	Sig.

Model's Summary
R = 0.18
R^2 = 0.000
Adjusted R^2 = 0.040

Dependent variable cost overrun

Table 4. Regression Analysis of the effect of the use of construction 4.0 on time overrun for housing delivery

	B	Std. Error	t	p-value	Remark
(Constant)	24.653	8.345	6.019	0.006	Sig.
Use of construction 4.0 principles	3.316	20.231	1.937	0.000	Sig.
Model's Summary R = 0.768 R^2 = 0.590 Adjusted R^2 = 0.547					

Dependent variable time overrun

Table 3 and 4 showed that at 95% and 99% confidence level interval there is a significant impact of the use of construction 4.0 on housing delivery about cost and time overrun as the p-value are lesser than 0.05 which implies. This confirms that the use of the innovations provided by construction 4.0 will have a tremendous impact on housing delivery strategies in South Africa.

5.0 CONCLUSION

The provision of Housing has always been the challenge of most developing nations due to the multifaceted nature of housing as it requires other amenities and infrastructures for the delivery of housing. In tackling this problem different countries have enacted diverse housing delivery strategies to reduce the backlog of housing production. Unfortunately, most of this strategy have not effectively reduced the housing shortage within the country including South Africa. This study proposes the fusion of construction 4.0 principles with housing delivery strategies towards reducing the housing backlog experienced in South Africa.

Construction 4.0 is based on the background of industry 4.0 that is known for its ability in changing the nature of performing an activity due to its support in the creation of new technologies that ensure modern methods for meeting existing needs. The use of construction 4.0 for housing will ensure that housing delivery strategies shift from a hierarchical structure towards a network of collaborative housing models that will create an avenue where the construction professionals, policy makers, and prospective house occupants work together to achieve a successful housing delivery.

Finally, the study concludes that there is a positive impact on the use of construction 4.0 principle for housing delivery as it reduced cost and time overrun thereby ensuring the prompt delivery of affordable and quality houses. The foremost hindrance to the adoption of construction 4.0 principle is the cost of investing in modern technology by small construction firms. The study contributes to the innovative ideas for housing delivery in South African it recommends that strategies and infrastructures should be put in place towards enabling the digitization of the construction industry and increase the awareness of construction 4.0 among construction professionals.

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Dry-mix autoclaved lunar concrete from lower-Ti basalt lunar regolith simulant

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Abstract

To build a permanently inhabited base on the Moon is a vitally important step to developing deep space exploration and lunar colonization. Therefore, indigenous materials become a significant requirement for lunar construction as transporting the construction materials from Earth is extremely expensive. Fortunately, construction materials can be fabricated by utilizing in-situ materials on the Moon. Dry mix autoclaving is a feasible process for lunar construction material manufacture. In this study, the influence of calcareous material ratio, LRS fineness and briquetting pressure on mechanical property was discussed to estimating the most appropriate technological parameter. The strength forming mechanism was expounded by the investigation of hydration products. The result shows that introducing appropriate amount of high-activity calcium materials can improve the strength and promote the generation of target hydration products. Meanwhile, the increasing of LRS fineness resulted in weakening of compressive strength which may ascribe to the decreasing compactness caused by the trapped gas during forming process with finer particles. The increment of briquetting pressure enhanced compressive strength in a certain range. However, it should be implemented after comprehensive consideration of the enhancing effect. This research provides support for preparation of autoclaved lunar construction materials in the near future.

Keywords: Lunar construction; dry-mix autoclaving; lunar regolith simulant; mechanical property; hydration products

1. Introduction

The long-term vision for space exploration includes developing human habitats and conducting scientific investigations on planetary bodies, especially on Moon and Mars. Lunar construction is a vitally important step in the exploration and colonization of the Moon and even the solar system [1]. Ascribing to the adverse effect of harsh environment on unprotected humans, the indoor environment has to be insulated from vacuum, radiation, extreme temperatures, dust, and meteoroids et al, by a protective structure [2]. Fabricating construction material in harsh Moon environment, especially vacuum and extreme temperature, with limited kind of resource and energy is extremely difficult.

Dry Mix/Steam Injection (DM/SI) technology is another feasible method for developing concrete on the moon. In DM/SI method, the dry mixture particles gradually heated and embraced by the hot steam, meanwhile, part of the steam being forced infiltrate into the inner regions of the component via the micropores, the mixture particles gain activation energy and moisture condensed from steam, undergo rapidly and hydration gradually. The DM/SI method has significant advantages than the wet mixing method, such as lower water and cement needed, faster and more thorough hydration and much shorter curing time. Meanwhile, DM/SI method prevented the material from being exposed to the vacuum and thus avoids the rapid evaporation of water [3]. The DM/SI method products can achieve higher strength than conventional cured products mainly owe to the more generating of C-S-H gel which resulted in

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a denser concrete structure [4,5]. Steaming technology can be separated into unsaturated and saturated steam curing. Unsaturated steam curing was commonly known as steam curing, and saturated steam curing with certain pressure was always named autoclaving process in term of material science. In this paper, the steam technology is referring to the autoclaving process.

The utilization of steaming technology in lunar construction material manufacture was firstly proposed and delivered promising results in 1989 by T.D. Lin and Su N [3,6]. T.D. Lin proposed the procedure of DM/SI process to overcome the ill-suited vacuum condition. The test program was carried out by National Chiao Tung University with cement and Ottawa sand. The concrete developed 700kgf/cm^2 (10000psi) after 18 hours of saturated steaming at 180 ℃. The compressive strength is approximately 2.5 times and half cement requirement to the conventional wet-mix procedure [7]. Nan Su of National Yunlin University of Science and Technology have discussed the characteristics and engineering properties of dry-mix/steam-injection concrete with cement and standard sand. The optimal steaming temperature for dry-mix samples of cement and standard sand is 180–200°C and the optimal steaming scenario for 10 cm^3 samples of concrete is at 200°C for 18 h. The present DM/SI method has advantages of lower cement content, shorter hardening time and higher concrete strengths, as compared to normal temperature wet-mix method [8]. S. Wilhelm and M. Curbach has verified the DM/SI method with lunar regolith simulant JSC-1A, which generated a compressive strength of 10.7 N/mm² and a water-cement ratio of 0.45 was calculated after one day procedure [9]. The steam injection hydration of high alumina cement concrete (mortar) and Ottawa sand has been characterized by D M Pakulski and K J Knox in 1992, a compressive strength of about 30 N/mm² after steaming for 25 min at 130℃ and 0.2 N/mm² steam pressure was achieved [10].

But above all, all of the researches were introducing cement as calcareous materials, ignored that the essence of the hydrothermal synthesis reaction is the hydration reaction between alkalinity calcium hydroxide ($Ca(OH)_2$-CH) and acidity oxide silicon (SiO_2, Al_2O_3, etc.). In addition, almost no research was considered the raw material chemical composition and mechanism of hydrothermal synthesis of raw materials based on complex mineral system design, and less on the influence of different particle size distribution of the research.

This research presented an autoclaved construction material prepared from lunar regolith simulant (LRS) and calcium hydroxide (CH) with saturated vapor pressure curing. The influence of calcareous material ratio, LRS fineness and briquetting pressure on compressive strength was discussed to estimating an appropriate mixture proportion and forming pressure. Meanwhile, the hydration products of CH and LRS autoclaved lunar construction material were determined to expounding the strength mechanism. This research provides support for preparation of autoclaved lunar construction materials in the near future.

2. Raw materials and methods

2.1 Raw materials

The major raw material LRS was collected and pretreated as the research of Zheng Yongchun et al [11]. The calcareous material was calcium hydroxide (CH) which was chemically pure reagent produced by Sinopharm Chemical Reagent Co., Ltd. The content of ($Ca(OH)_2$) was exceed 99.95%.

2.2 Mixture proportion

The mixture proportion of each specimen was shown in Table1. Group D1-D9 was set to determine a more appropriate mix proportion. Group D7, D10, D11 were carried out to evaluating the effect of LRS fineness of the mechanical properties of the final products. Finally, the effect of briquetting pressure was determined according to mixture proportion in Group D7.

Table 1 Mixture proportion of specimens

No	Calcium hydroxide	LRS	LRS Fineness	Ca/Si	K_{alk}
D1	0%	100%		0.18	0.09
D2	5%	95%		0.26	0.18
D3	6%	94%		0.28	0.2
D4	7%	93%		0.30	0.22
D5	8%	92%	＜65Mesh	0.32	0.24
D6	9%	91%		0.34	0.26
D7	10%	90%		0.36	0.28
D8	15%	85%		0.47	0.39
D9	20%	80%		0.60	0.51
D10	10%	90%	＜150Mesh	0.36	0.28
D11	10%	90%	＜200Mesh		

2.3 Specimen preparation

The materials were first weighed according to the mixture proportion, and then mixed in an electric mixer for 3mins. The mixture was decanted into a cylinder pelleting mould and compacted with press machine at specified pressure (50KN) and dwell time (10s). After that, put the rough-body into an autoclave for steaming process. The autoclaving saturated vapor pressure was maintained at 1.4MPa, corresponding to 190℃, for 8h. After arriving at the designated maintenance time, turning off the power and waiting for the chamber cool down to room temperature to take out the specimens.

2.4 Characterization

The chemical component of LRS was detected by X-ray fluorescence spectrometer. The specific surface area of LRS was carried out according to GB/T 8074-2008. The granulometric distribution of LRS was determined by laser particle size analyzer, Marlvern Mastersizer 2000. The compressive strength was measured by a concrete compression testing machine with ±1% error. The morphology of hydration product was characterized by using JEM-2100F field-emission high resolution transmission electron microscopy (FESEM) and energy dispersive X-ray (EDX). The mineral constituent of LRS and autoclaved product were detected by a D/8 Adwance X-ray diffractometer with Cu Kα radiation from 5°-70°. The parameters of the characteristic peak of autoclaved samples were determined by Jade 5.0.

3. Results and discussion

3.1 Lunar regolith simulant

The chemical component of LRS was shown in Table 2, meanwhile, the morphology and mineral composition was presented in Fig1 and Fig 2, respectively. From the analysis of LRS particle morphology, the ground LRS particles were angular, which is ascribe to the brittleness of basaltic material in the grinding process. The dominant oxides in LRS were SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO, accompany with Na_2O, K_2O, TiO_2, MnO and P_2O_5. From the angle of mineral composition, LRS mainly consisted of feldspar, pyroxene and olivine which existed by 63.5%, 22.3% and 8.1%, respectively, according to CAS-1 lunar soil simulant [11]. The LRS with different fineness were achieved by grinding and filtrating process and the granular characteristics of LRS presented in Fig 3.

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Table 2 chemical component of LRS

Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Loss
LRS	48.23	18.29	11.19	7.89	4.41	3.70	2.15	2.96	0.20	0.50	0.55

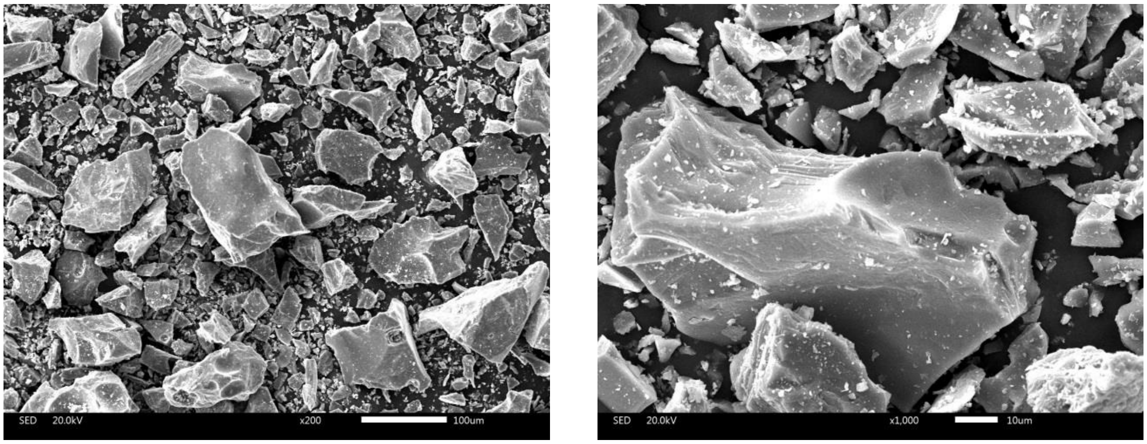

Fig 1 Morphology of LRS particles

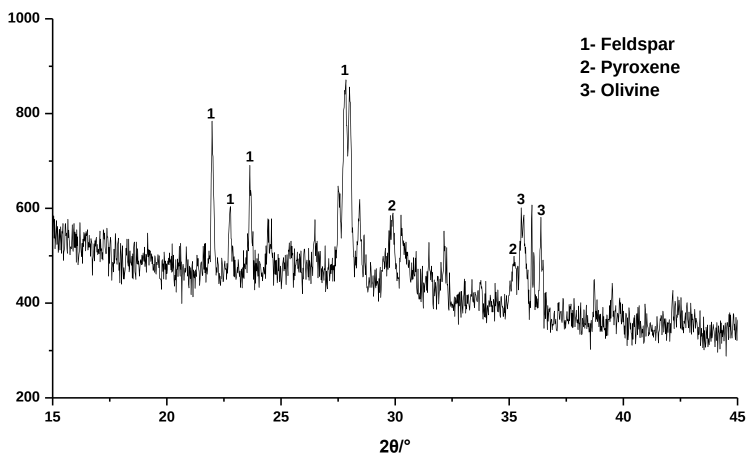

Fig 2 Mineralogical analysis of LRS

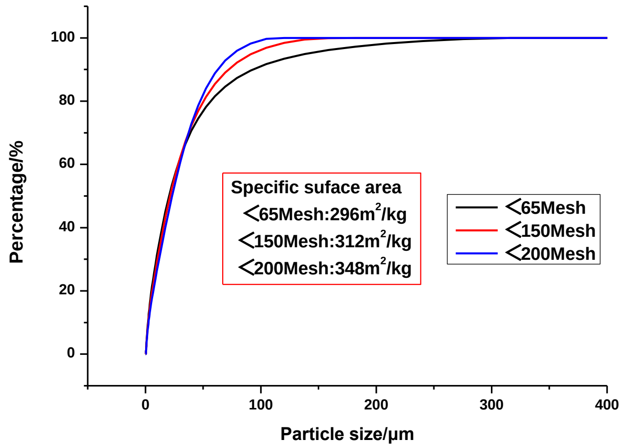

Fig 3 Granular characteristics of LRS

3.2 Chemical analysis

In term of chemical and mineralogical composition, LRS is a multi-mineral material with SiO_2 and Al_2O_3 as main components and CaO and MgO as minor components. Therefore, the mixture proportion of autoclaving technology should refer to the alkaline coefficient (K_{alk}) between 0.8~1.2. The formula of K_{alk} was shown in Eq.(1). The K_{alk} of LRS was 0.03, indicating that it was characteristically acidic, Consequently, alkaline correction materials, like calcium oxide (CaO) and calcium hydroxide ($Ca(OH)_2$) should be added to modify the K_{alk} of the mixture to be a more appropriate value range for preparing autoclaved products. However, due to the dry mix process, addition of CaO will cause serious volume expansion during steam pressure curing process which cannot be neglected. Thus, $Ca(OH)_2$ was chosen as the K_{alk} modification material [12].

$$K_{alk} = \frac{[(CaO + 0.93MgO + 0.6R_2O) - (0.55Al_2O_3 + 0.35Fe_2O_3 + 0.7SO_3)]}{0.93SiO_2} \quad (1)$$

3.3 Calcareous material ratio

The effect of calcareous material ratio on compressive strength was carried out to evaluate the most appropriate calcium-silicate ratio and K_{alk} of dry-mix autoclaved lunar concrete from lower-Ti basalt lunar regolith simulant. Meanwhile, in consideration of the rarity of calcium hydroxide on the Moon, CH content should be as low as possible under sufficient strength.

The samples and compressive strength values were shown in Fig 4 and Fig 5, respectively. With the CH content increasing from 0% to 20%, the surface of the sample gradually became dense, which indicated the improving reaction rate between LRS and CH. Meanwhile, the compressive strength enhanced from quite brittle (0.2MPa) to high intensity (49.63MPa) also verified the regulation. Nevertheless, in view of sufficient strength and restricted CH supply, 10% CH content was chosen as a reference group for the following experiment. Taking the long view, the performances of construction materials under lunar extreme environment still need further investigation.

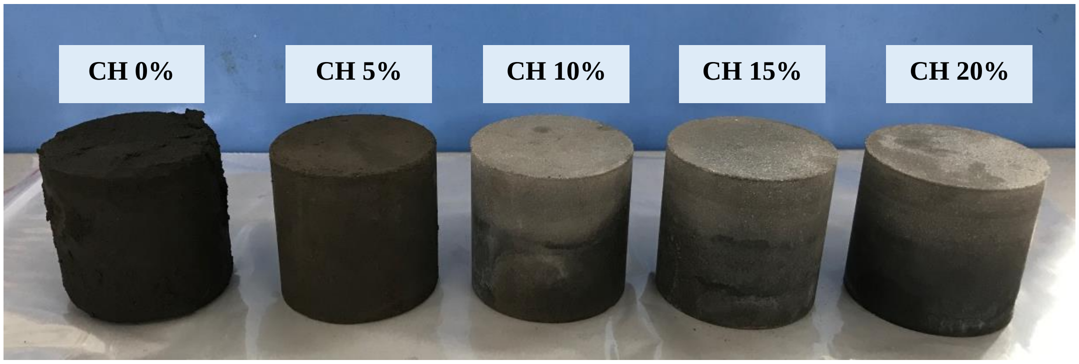

Fig 4 Specimens of different calcareous material ratio

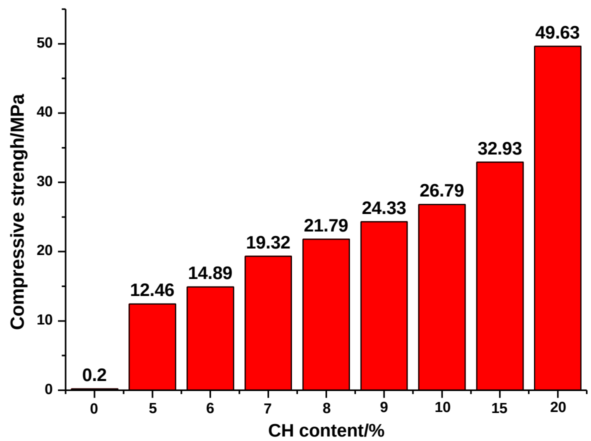

Fig 5 Compressive strength of different calcareous material ratio specimens

3.4 Lunar regolith simulant fineness

In consideration of the grinding and filtrating process on the moon is uncomplicated, and the supplying of various fineness lunar regolith is realizable. Meanwhile, from the angle of reaction activity, increasing fineness can improve mechanical properties to a certain extent. Therefore, the influence of LRS fineness was investigated to determine the optimal granularity characteristics of LRS for dry-mix autoclaved lunar concrete.

The samples and compressive strength values were presented in Fig 6 and Fig 7, respectively. It can be seen that with the finer of LRS, it cannot tell obvious difference from appearance, but an anomalous regulation revealed in the compressive strength value. The weakening of compressive strength may ascribe to the decreasing compactness which caused by the trapped gas during forming process with finer particles. Nevertheless, this problem can be effectively avoided in the ultra-high vacuum environment on the Moon. On all accounts, powder compacting component has an optimized particle size distribution range, not pursue the reaction activity blindly, but neglected the problem of powder filtration and formation.

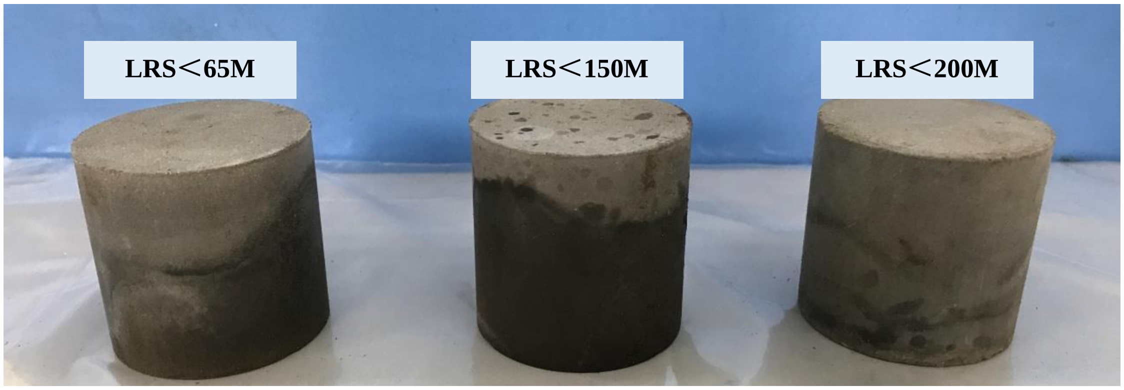

Fig 6 Specimens of different LRS fineness

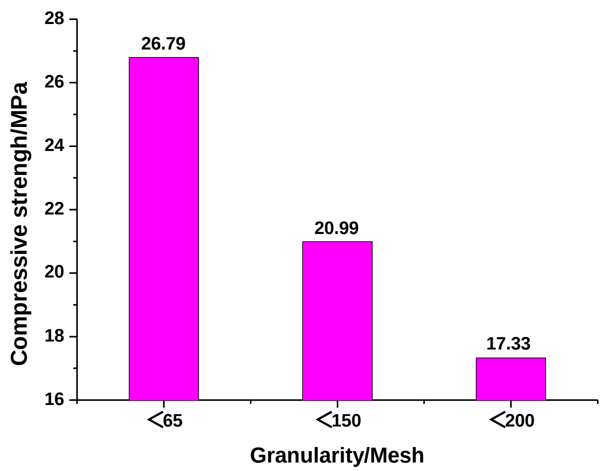

Fig 7 Compressive strength of different LRS fineness specimens

3.5 Briquetting pressure

On account of the influence of different briquetting pressure (25KN, 50KN, 75KN, 100KN) on compactness, and finally resulted in different density and compressive strength, it was investigated to determine a better molding force value. The result was presented in Fig 8. It can tell that with the briquetting pressure gained from 25KN to 100KN, the compressive strength enhanced from 20.09MPa to 29.53MPa. When briquetting pressure enlarged from 25KN to 50KN, the compressive strength increased more than 33%. Nevertheless, keep on increasing briquetting pressure to 100KN can improve the compressive strength by only 10%. Therefore, the increment of briquetting pressure should be implemented after comprehensive consideration of the enhancing effect.

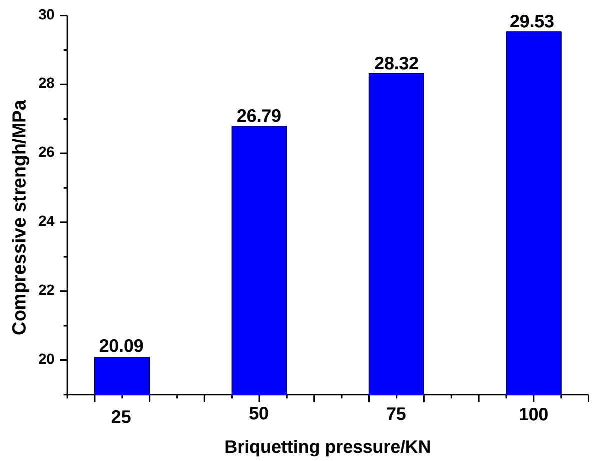

Fig 8 Compressive strength of different briquetting pressure specimens

3.6 Analysis of hydration products

In order to figure out the morphology features and mineral composition of dry-mix autoclaved lunar concrete from lower-Ti basalt lunar regolith simulant, analysis of hydration products was carried out by FESEM-EDS and XRD method, respectively.

The morphology of sample D7 was presented in Fig 9 and Fig 10, and the elemental quantitative analysis was listed in Table 3. As Fig 9 shown, plenty dough-like phase which supposed to be C-S-H gel (Spot2) adhered to LRS particles, meanwhile, some areas has formed faveolated crystal which should be low crystallinity tobermorite (Spot1). As the 5000 times magnified picture in Fig 10, flake-like products (Spot 3) were generated on LRS particles which believed to be well crystallinity tobermorite(Spot 4). The particles were adhered with adjacent by C-S-H gel and tobermorite which resulted in interconnected structure and acquire strength.

As the mineralogical analysis of sample D7 in Fig 11, besides the unreacted minerals of LRS, adscititious $Ca(OH)_2$ (4.9Å, 2.67Å) and generated tobermorite (11.3Å, 3.08Å) were also detected in the autoclaved products. The amorphous C-S-H gel cannot came into sharp feature peaks but emerged broadened ‘‘convex closure” between 26~34°. Thus, the mineralogical analysis presented the similar mineral composition with morphology analysis.

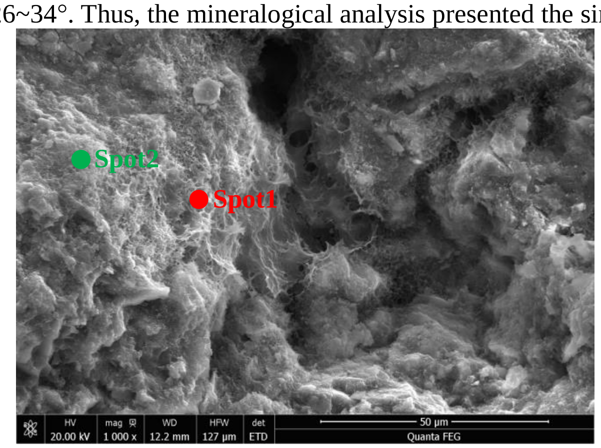

Fig 9 Mineral morphology of sample 7 (Ⅰ)

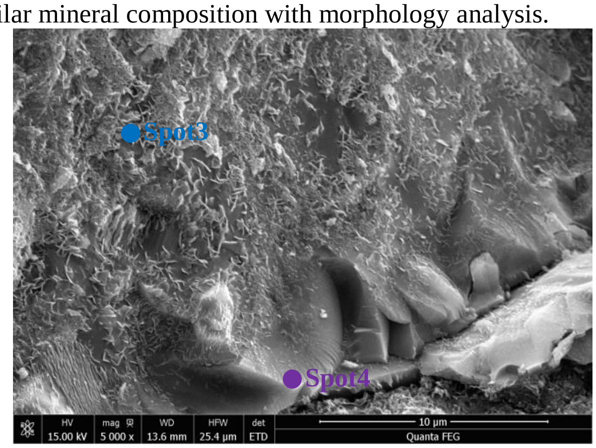

Fig 10 Mineral morphology of sample 7 (Ⅱ)

Table 3 Elemental quantitative analysis

Elements	Spot1		Spot2		Spot3		Spot4	
	Weight/%	Atom/%	Weight/%	Atom/%	Weight/%	Atom/%	Weight/%	Atom/%
Ca	10.94	6.04	9.32	5.30	6.94	3.88	4.74	2.54
Si	17.62	13.87	18.42	14.96	21.62	17.24	21.10	16.12
O	44.04	60.89	40.02	57.03	41.46	58.03	45.78	61.39
Al	7.42	6.08	6.97	5.89	8.25	6.85	9.38	7.46
Mg	3.84	3.49	6.22	5.83	3.44	3.17	2.42	2.14
Na	4.53	4.36	4.32	4.29	4.68	4.56	5.87	5.48
Fe	7.39	2.93	10.38	4.24	8.01	3.21	5.48	2.10

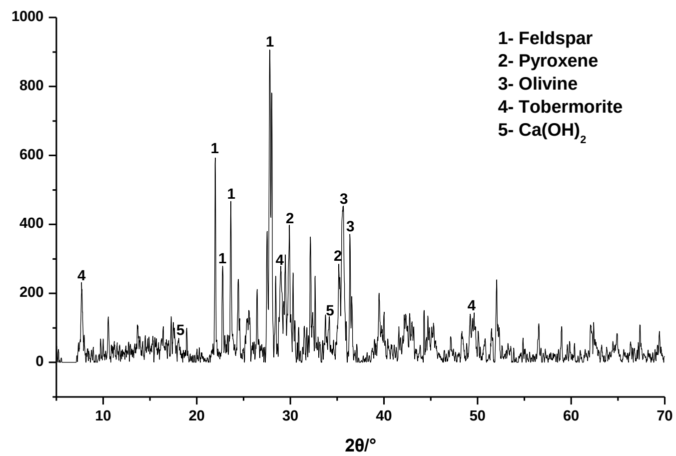

Fig 11 Mineralogical analysis of sample 7

4. Conclusion

This paper investigated the influence of calcareous material ratio, LRS fineness and briquetting pressure on mechanical property; meanwhile, the hydration products were determined to expounding the strength mechanism. The following conclusions can be drawn:

(1) The increasing of CH content effectively enhanced the compressive strength. However, finer of LRS has adverse effect on the mechanical property. Although, increment of briquetting pressure can improve mechanical property in a certain range, it should be implemented after comprehensive consideration of the enhancing effect.

(2) Through autoclaving process, mainly generated amorphous C-S-H gel, faveolated low crystallinity tobermorite and flake-like well crystallinity tobermorite. The strength was attributed to the interconnected structure formed by adhering of C-S-H gel and tobermorite.

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Initial investigation of generating electricity from concrete

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Abstract

Cement heat of hydration (HH) can be problematic especially in mass concrete structures as it causes thermal stresses that can lead to failure. Previous and current research has focused on minimizing the HH and mitigating its effects. The methods currently used for treating the HH in mass concreting varies between using: adding supplementary material to concrete, precooling of aggregates and mixing water, post-cooling of concrete, insulation of concrete members, and placement of concrete in thin lifts. These methods result in adding more cost and time to the construction project. This research sheds the light on a new approach in treating the cement HH. The paper presents initial experimentations conducted to dissipate the HH from the body of a concrete structure and convert it to electricity. This research should prove useful in laying the foundation for the development of more sustainable construction methods for mass concreting.

Keywords: Heat of hydration; mass concrete; construction methods

1. Introduction

Cement heat of hydration (HH) can cause serious problems in mass concrete structures. The HH can lead to thermal expansions due to the difference in the temperatures inside the concrete and on the surface [1,2,3,4]. The outer surfaces cools faster than the internal concrete, which leads to thermal contractions. This phenomenon induces thermal (tensile) stresses on the surface of concrete, which may lead to the failure of the structure entirely. Most codes require that the temperature difference in concrete members does not exceed 35°F [1, 2]. Another problem exists when the HH increases the internal temperature of concrete above 158°F. This can lead to delayed ettringite formation, which leads to the expansion and cracking of concrete [1, 2].

Although the construction mass concrete members are frequent especially in commercial and institutional buildings (Ex. Sky Scrapers), and infrastructure and heavy construction (Ex. Water Dams), the advancement in the construction methods for mass concreting has been very negligible over decades. The methods of construction used in mass concreting have been: a) insulation of concrete members, b) precooling of the mixing water (mixing with ice and/or liquid nitrogen), c) precooling of the aggregates, d) post cooling of concrete (cooling pipes), and d) placement of concrete in thin lifts [1,2,3,4]. The quantification, problems, and treatment of negative effects of the cement HH have been investigated in a multitude of studies. The majority of these studies regarded the HH as a threat to the structural integrity of the mass concrete members. As such, the approach in dealing with the HH has been directed toward minimizing the heat released, and controlling the concrete temperature. Not only are these approaches costly and time consuming, but also they are unsustainable.

In this proposed research, the authors' philosophy is that the HH is an unutilized source of energy; and they foresee a golden opportunity in converting it to electricity using the available technology in thermoelectric conversion. In the first experimentations, the possibility of capturing the HH and convert it to electricity was proved and demonstrated.

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2. Problem and objective

The main problem that this research is aimed at solving is the negative effect of the HH on the integrity of mass concrete structure as it leads to thermal stresses due to the temperature gradient existent between the surface and the interior of concrete. Another problem that stems from the increase in might occur on the long run is the formation of delayed ettringite which causes expansion and cracks inside the concrete [1,2,3,4].

The proposed construction method serves as a sustainable alternative for the existing methods. The current methods for treating the HH can be classified into construction methods and the incorporation of supplementary cementitious material in the concrete mix. The construction methods category includes techniques such as precooling, post cooling, insulation, pouring concrete in thin lifts. Several studies and articles have addressed these construction methods, as in [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14]. Other studies have focused on the effect of supplementary cementitious materials such as fly ash and silica fume on the cement HH, as in [15, 16, 17, 18, 19, 20, 21, 22, 23, 24]. Not only do these traditional methods increase the construction cost and time, but also they have their negative impacts on the environment and the communities surrounding the project location.

The main objective of this research is to investigate the possibility of overcoming the negative effects of the HH by dissipating it from the body of concrete and converting it into a useful form of energy. This should lay the foundation for the development of more sustainable construction methods that can be used for treating the HH in mass concreting.

3. Methodology

This research focuses on the development of a new sustainable construction method for eliminating the negative effects of the HH in mass concrete members by converting it to electricity. In simple words, if the HH could be harvested and converted to a useful form of energy (electricity), then not only the thermal expansion problems would be solved but also additional revenue would be generated, which is the free green electricity. To achieve this goal, the field of energy harvesting and thermoelectric conversion provides a viable alternative to dissipate this heat from the body of a concrete structure and turn it into "green" electricity. Thermoelectric conversion refers to the direct conversion of heat to electricity using thermoelectric converters. There are two types of thermoelectric converters: 1) Thermoelectric Generators (TEG), and 2) Thermoelectric Coolers (TECs). TEGs and TECs can be used in two ways. If the two sides of the TEG or the TEC plate are subjected to temperature difference, voltage will be produced. If voltage is applied across the TEG or TEC peltier, one side will be cold and the other will get hot. TECs are optimized for cooling. They are usually used in making coolers. TEGs are mainly used for electric current generation. A typical TEG peltoer is shown in Fig. 1.

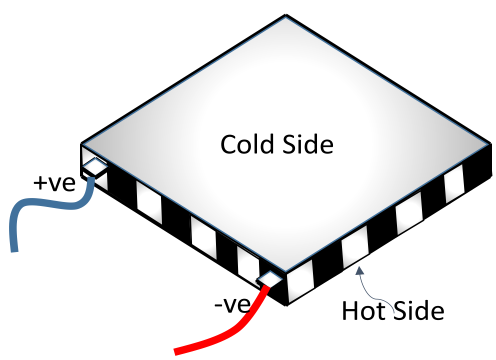

Fig.1: TEG peltier

4. Experimentation

A series of experiments were conducted to better understand and optimize the use of thermoelectric generators (TEG) and Thermoelectric Coolers (TECs) peltiers. Peltier is the TEG or the TEC module used for thermoelectric conversion as shown in Fig.1. Different types of TEGs and TECs from different manufacturers in China, USA, and Canada were investigated for their potential use in the proposed construction method.

4.1. Initial experimentation

In the initial experiments, the objective was to test the suitability of TEG and TEC peltiers for the proposed research. In these experiments, a source of heat was used to directly heat the hot side of a single peltier. Candles or hot water were usually used in exploratory experiments. A heat sink was placed on the other side of the peltier (cold side) to create a temperature gradient. The two ends of the peltier were connected to a load (multimeter or LED light) as shown in Fig. 2. Cooper and Aluminum heat sinks were used for cooling the peltiers. The conclusion of the initial experiments was that TEG peltiers are more efficient than TECs in generating voltage and current. Also, it was found that it is really hard to maintain a steady volt or current over a long period of time. Copper heat sinks proved to be more efficient in dissipating the heat than aluminum heat sinks.

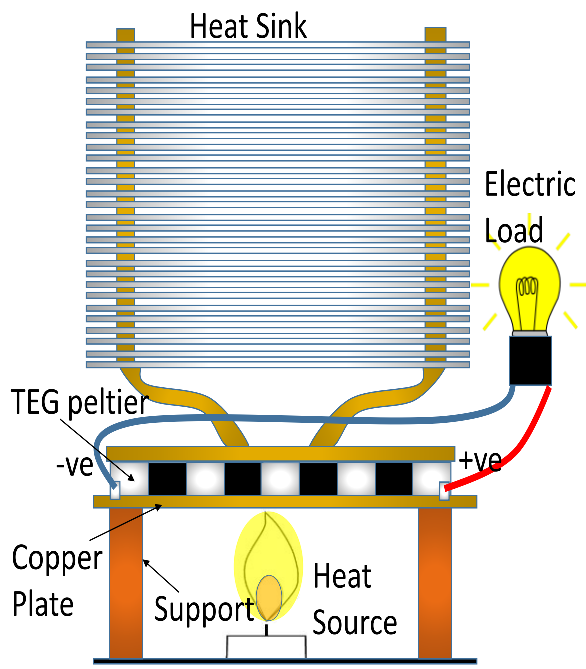

Fig. 2: Typical Heat Harvesting Setup

4.2. Conversion of heat of hydration to electricity

The conclusions of the initial experiments served as bases for designing the first experiment conducted for harvesting the heat of hydration from the core of concrete and its conversion to electricity using thermoelectric electric generators. For this experiment, the construction of a raft (matt) foundation was simulated. A rectangular plastic container was filled with cement paste. The dimension of the pseudo-raft foundation was of a dimension of (17 x 13.5 x 4.5 inch). The total amount of cement used was 59 lb, and the W/C ratio was 0.3. The W/C was selected particular low to minimize the heat of hydration released. It is known that the higher the W/C ratio, the higher the hydration, and the higher the heat released. As such, to prove the concept that the HH can be harvested form the core of concrete and converted to electricity, the experiment was designed to represent the worst-case scenario. First, the quantity of cement used was so little compared to real life application. As such, the amount of heat release was estimated to be insignificant and too little to be harvested. Second, the W/C was reduced purposely to reduce the amount of heat released to make it even more difficult to generate electricity since sufficient heat is required for the the TEG to work properly.

Copper heat pipes were inserted inside the paste to harvest the heat. The copper pipes were 200 mm in length and 10 mm in diameter. The pipes were bent to form 45°angle with the surface of the cement paste to maximize the contact with the zones of the highest temperatures across the horizontal and vertical dimensions of the cement paste, as shown in Fig. 3. Each 4 pipes were grouped together to form a base that has dimensions of 40 x 40 mm for TEG peltiers. Six bases were formed to accommodate 6 TEG peltiers. The peltiers were divided into two sets. Each three TEG peltiers were connected in series; the two sets were then connected in parallel.

The temperature inside the concrete started to rise gradually. Usually, the temperature reaches its peak after 6 to 7 hours of mixing cement with water. After 6 hours, the temperature recorded on the surface of the copper heat pipes using an infrared thermometer was above 60°C. The hot side of the TEG peltiers was placed directly on top of the pipes; the volt and the ampere were then recorded (1 Volt and 0.1 ampere). Copper heat sinks were placed on top of the cold side to create a temperature gradient, which raised the output electricity to 5 volts and 1.2 amperes.

This small "concrete battery" was used to light 4 LED light bulbs at the same time, turn a small motor on, and charge a cell phone. Future experiments will focus on achieving the research objectives which focuses on finding the most effective way of harvesting the HH, quantifying and maximizing the electricity generated, using Type III cement, and exposing a broad spectrum of the society to innovative methods of sustainability.

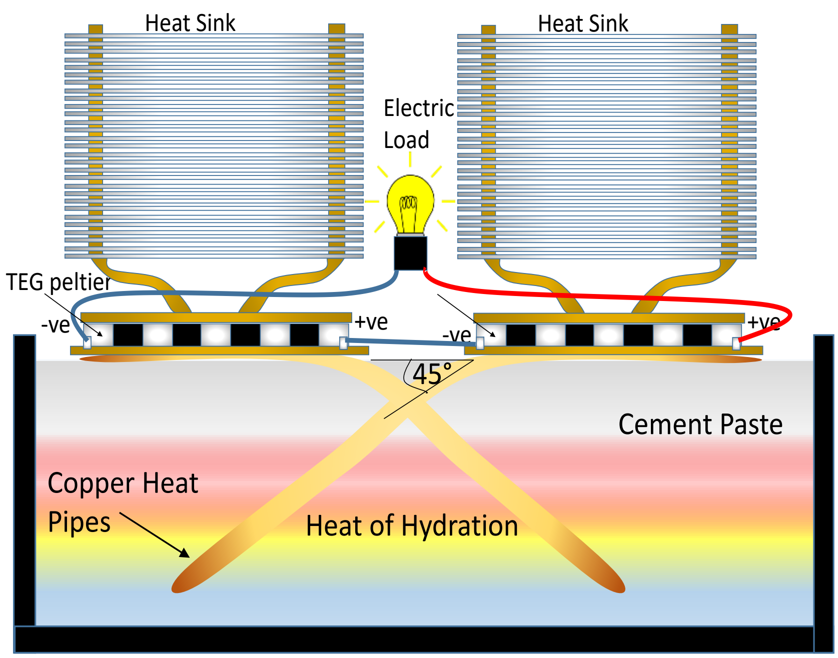

Fig. 4: Generating electricity Using HH

5. Discussion

The proposed method is expected to expedite the construction through the efficient harvesting of the HH. For instance, this will allow the continuous placement of concrete rather than placing it in thin lifts [25]. This in turn will save a lot of time and cost and will minimize the impact on the environment, economy, and society. Cost savings will be realized through the minimization of the idle time resources, and the need for additional material such as cooling pipes or insulation sheets for the concrete members. For example, the Hoover Dam required about 582 miles of cooling pipes [26, 27].

The proposed method contributes to the protection of the environment - unlike other construction methods- as it does not require any energy for operation. On the contrary, this method will generate energy.

Another point is that the proposed method will not only dissipate the HH from the core of the concrete structure but it will also convert it to electricity avoiding its release in the atmosphere, which contributes negatively to the problem of global warming. Each gram of cement – When hydrated- releases 3 calories of heat in the atmosphere [28, 29]. A cubic meter of concrete contains 400 Kg of cement on average. This means that 1 m3 of concrete can generate 23 Watt hour using thermoelectric generators working with 5% efficiency. On average, a cell phone requires 5 watts for 50

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minutes to charge completely. As such, the electricity that can be generated from 1 m3 of concrete using thermoelectric conversion can be used to charge 4 cell phones fully.

The effectiveness in the continuous harvesting of the HH proposed in this research will encourage the use of Type III cement (high early strength), and taking advantage of its benefits. This will lead to rapid construction which will minimize time, money, and the negative impacts on the environment. Similarly, the proposed construction method will encourage the research for the development of nano cement, which is expected to have a lot of benefits, but its main problem will be the huge amount of HH that will be released [30, 31, 32].

A very important point that signify this research is its interdisciplinary nature. The application of heat harvesting and thermoelectric conversion in construction operations has been very limited. This opens the door to researchers to use the same or similar concepts in other application in construction, such as the thermoelectric application in geothermal piles.

6. Conclusion

This research proposes the development of a new sustainable mass concreting construction method. The proposed method utilizes the available technology of thermoelectric conversion to dissipate the heat of hydration from the core of concrete and convert it to electricity. The further development of this method can have several advantages that contribute to solving several problems associated with the construction industry. The first problem that the proposed method can contribute positively to is the minimization of material use such as supplementary cementitious materials or cooling pipes to treat the heat of hydration. In turn, this will minimize the construction cost and time. The second advantage is the promotion of green construction and reduction of CO2 emissions. The generated electric energy can be stored and used for site operations. This will save on carbon fuel and promote greener and more sustainable construction especially in remote construction sites. The proposed construction method can lead to the minimization of the contribution of the cement heat of hydration to global warming by converting some of this heat to electricity rather than releasing it in the air. Finally, if this research proved successful, it would encourage the development of nano cement, which is expected to have a lot of benefits, but its main problem will be the huge amount of HH that will be released.

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Maintaining Building Function During a Fire Event: Analysis of Hospital Fire and Smoke Control Systems

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Abstract

Fires in a critical facility such as a hospital could lead to catastrophic outcomes if the fire and smoke control systems are not properly installed, monitored, and maintained. This research studied a single facility and its smoke management system, primarily focusing on the HVAC system and how it responds in the event of a fire. Key facilities management staff were interviewed and national life safety codes were reviewed. The research indicated that each facility is going to operate completely different due to the differing needs; however, care must always be taken to properly locate functional hospital units in corresponding smoke zones to minimize the loss of a functional healthcare system after a fire event. Additionally, the need to digitize and centrally monitor all aspects of the smoke and fire control system is clearly evident, as this will provide a system that can be repaired quickly and efficiently.

Peer-review under responsibility of the scientific committee of the Creative Construction Conference 2018.

Keywords: smoke, fire, control, HVAC, zone, damper, sprinkler, atrium;

Introduction

Have you ever wondered what would happen if a hospital caught on fire? Would they have to evacuate everyone? Would they be able to triage the people injured by the fire? Generally speaking, hospitals are set up to contain smoke and fire to an area designated by certain building codes and design layout. There are active features, such as automatic sprinklers, mechanical systems, and smoke evacuation fans and there are passive features like fire and smoke dampers and physical barriers. The combination of these features provides assistance to contain and control a fire to a certain area. The ability to control fire and smoke is extremely important, as it is an essential function in order to protect occupants in a building. These items are not in place to protect the contents of the facility, as much as they are there to protect the people who may not be able to evacuate without a great deal of assistance, and the staff that care for them.

This research discusses the intent and design of a key piece of this entire system, the Heating Ventilation and Air Conditioning (HVAC), and looks toward the future and how these systems can be improved upon. This is especially important to hospitals that are undergoing massive construction and remodelling projects to maintain a facility that is able to provide efficient and effective patient care.

Literature Review

In reviewing previous research literature for this topic, a significant amount of research was completed in the 1980's; however, it seemed to taper off until the 2000's. The most largely researched topic in this field is fire and smoke

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dampers. Fire dampers are rarely activated, as they are required to get to a high heat prior to activating. Smoke dampers may activate once the system senses smoke.(Felker, 2008) These systems can be very simple in design where the entire supply side of the system shuts down once smoke is detected, or amazingly complex where many systems are intertwined with each other like dampers, logic-based HVAC, automatic sprinklers, mass notification system, fire alarm, and building automation. (Banse, 2006). The HVAC systems don't seem to be studied much as they are generally programmable and will vary from facility to facility.

Additionally, there are multiple national code manuals that have extensive information and guidance on how these systems are designed, installed, and maintained. The National Fire Protection Association (NFPA) is one of the leading organizations that provide guidance on fire, electrical, and hazard related items. NFPA 101 Life Safety Code discusses topics such as requirements for new and existing health care facilities. This code manual discusses fire and smoke rated walls, fire stopping, automatic door releases, dampers, and many other items involved in the life safety of a health care facility. It also discusses other types of facilities, but health care facilities are the primary focus of this paper. ("NFPA 101: Life Safety Code®," 2015) NFPA 99 Health Care Facilities Code establishes risk and facility requirements based on this risk to patients, staff, and visitors to health care facilities.("NFPA 99: Health Care Facilities Code," 2015) Finally, NFPA 92 Standard for Smoke Control Systems details how there are two (2) different types of systems: dedicated and non-dedicated. The dedicated systems have equipment installed for the single purpose of providing smoke control. Non-dedicated systems change the normal equipment to provide this service in the event of smoke detection.

Background

As hospitals continue to grow, the need for proper space planning and facility management grows with it. For example, an area that was built thirty years ago for a specific use may no longer be the same as it was when the space was built. Areas that were once in-patient wards are now out-patient clinics or community living centers, cafeterias have become more streamlined, and open space for family and patients to wait for their appointments has increased. Additionally, pharmacy needs have grown, emergency care needs have changed, and specialty equipment has improved significantly over the years. These are only just a few of the changes that have occurred over the years. Each time a hospital's needs change – they cannot tear down the building and start over again. They must remodel the space.

All of these changes require changes to the way the facility is managed and how the space is planned. In the event of a fire, many things need to function in a proper sequence to consider the control of a fire to be successful. Magnetic door holds may need to release, HVAC systems may need to change or stop flow. Automatic sprinklers may need to release. The mass notification systems required to alert the area and emergency lighting needs to be properly light the exit paths for the area.

In a hospital, the HVAC system is one of the largest and most important components of this entire facility. It is responsible for maintaining temperature and humidity, as well as replacing the building air with fresh outside air. Also, there are strict requirements for how many times the air in a certain space is replaced.("EC.02.05.01 - Clinical Impact | Joint Commission," n.d.) This helps with infection control in an area where patients are especially vulnerable due to weakened immune systems. Finally, the HVAC system is one of the primary responders in the event of a fire, with the ability to remove smoke from an area, starve the fire for oxygen or provide a smoke free pathway to safety. If properly equipped, the system will be able to contain the fire event, with the aid of automatic sprinklers, to a designed smoke control zone. This containment should be capable of maintaining this space for a designed amount of time until the first responders arrive on site.

Purpose of Study and Research Objective

Engineered fire control is a vast expanse of mechanical and electrical systems that all tie together: this study will focus mainly on the heating ventilation and air conditioning (HVAC) systems and the associated controls around its function during a fire event. Since it is tied to many other systems, if the system doesn't properly function, other systems risk becoming less effective.

The objective of this study is to increase awareness of the importance of these systems and their maintenance as well as requirements for upgrading the systems when necessary. Hospitals throughout the world may have the capabilities

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to perform a mass evacuation of the entire hospital, but this always a last option. If a mass evacuation was required, one may consider the following:

1. Where would the patients go?
2. What happens if they are connected to life support or oxygen? How long do mobile devices sustain this need?
3. Are there enough staff in a hospital to perform this type of evacuation?

In the event of a fire, the hospital would much rather evacuate a specific area of the hospital while the other areas are able to maintain function as normal. The other areas can take on the patients of the evacuated area, but the displaced patients are at much less risk than being completely evacuated from the facility with the need to be relocated to another hospital in the local vicinity.

For the purpose of this study – a specific facility is going to be detailed as the author has the ability to access the entire facility and staff for research purposes. The facility will not be named for public safety reasons, due to the risk that some of the details in this writing could be used improperly. This hospital has over 4000 rooms with a combined usage space of over 1.5 million square feet. The facility has fully functioning emergency department, community living center, outpatient clinics, 20+ operating rooms, and ambulatory care units. There are over 2700 staff on site on a normal workday and approximately 200 patients that do not leave the facility at the end of the day. The number of people that visit the facility (including family members and patients there for a regular appointment and will leave before the end of the day) is not monitored. The building construction was completed in the late 1980's for approximately $200 million. Over the years, the facility needs have evolved since the new facility was opened. With the changing needs, there is a greater need for larger and more complex construction projects. These projects change areas significantly; therefore, life safety designers are responsible for ensuring that the proposed renovations will allow the facility to meet its requirements.

Rational for the Study

Generally, causalities in hospital fires are low, compared to other building structures. This is due to the increased requirements for proper design and control of the systems that can aid in the containment of a fire event. However, the need still exists. From 2012 to 2014 there were over 1,100 fire in hospitals in the United States, and approximately 27% of these fires were non-confined fires, meaning that they were larger structure fires.("Hospital Fires (2012-2014)," n.d.)

These relatively small number could easily become catastrophic if the engineered fire and smoke systems that are in place were not there, or if they were to fail. In the early and mid-1900's it was not uncommon for there to be many deaths in hospital fires. 129 people died in the Cleveland Clinic in 1929, 16 people died in the 1961 Hartford Fire in Connecticut. Even in more recent past there have been deaths in hospital fires including 6 in Virginia in 1994 and 3 in New York in 1993. (Ahrens, 2012)

Loss Measures for Hospitals and All Other Medical Facility Fires (Three-Year Average, 2012-2014)

Loss Measure	Hospital Fires	All Other Medical Facility Fires
Average Loss:		
Fatalities/1,000 Fires	0.4	0.6
Injuries/1,000 Fires	17.3	19.6
Dollar Loss/Fire	$6,030	$11,290

Source: National Fire Incident Reporting System (NFIRS) 5.0.

Figure 1 – Loss Measure for Hospitals and All Other Medical Facility Fires. ("Hospital Fires (2012-2014)," n.d.)

Looking at Figure 1 above, hospitals have generally been a safe place to be in the event of a fire, but there is still room for improvement. Additionally, while the numbers may be low, a value that is not reported here would be the amount of time lost to cleaning and repairing the area that was affected by the fire. If an area that generally houses 20-30 overnight patients, those patients will need to be relocated and the area is required to undergo full inspection

and cleaning. Most wards in the studied facility are approximately 12,000 SF, which is contained in a single smoke control zone. This entire area would be closed until a full-scale remediation and investigation was completed.
While it appears that hospitals have control of their ability to control smoke and fire, the ever-moving target for efficient and effective patient care has caused these facilities to undergo massive remodelling and construction projects that change the overall layout of the originally designed space. If fire and smoke control is not given high priority during these designs, a major flaw is lingering in the background that can create critical and life-threatening outcomes. The need to verify that the facility is maintaining the most efficient and effective manners of smoke and fire control is critical due to these changes.

Research Design

In order to best understand the facility that is under review, plus understand the national design requirements, this study will use a qualitative research design. Research papers and national codes and standards will be reviewed and then the facility under the study will be analyzed and interviews will be performed with staff that is intimate with the system. A comparison of the research will be completed which will provide a conclusion of how the facility should be maintaining and upgrading its system as it moves forward into the future. The interviews will cover three separate groups of hospital staff:

1. HVAC Facilities Engineering Staff (2 employees)
    a. This is the staff that maintains the air-handling units as well as monitors the fire and smoke dampers. Since the sprinkler lines are monitored for flow and tied to the HVAC system, this staff also monitors these items.
2. ATS Facilities Engineering Staff (1 employee)
    a. This is the staff that maintains all of the building automation systems including, fire alarms, smoke detectors, automatic and magnetically held doors, and the mass notification system.
3. Safety and Emergency Management Staff (2 employees)
    a. This is the staff that maintains the evacuation plans as well as upgrading and testing policy and procedures. They develop standard operating procedures for the facility and have the knowledge of how the facility as a whole is designed to respond to a fire event. They also compile data required to be submitted to various local, state, and federal agencies during an inspection.

While the sample set is small, this interview will cover over 85 years of expertise and some of these staff have been with this specific facility since the early stages of this building being operated. They have witnessed the changes and upgrades over the years and have the most specific knowledge of the systems strengths and weaknesses. The 10 interview questions will remain the same across all of the interviewees, as each will provide their knowledge of that item. Additionally, the questions asked are intended to open to floor for further discussion into the depth of the interviewees knowledge. A set of the interview questions can be found below. This information will be combined to develop the integrated answer of how the facility operates through a multitude of connected systems. This also shows how complex these designs can become and how the need for clear and concise communication is key in a facility of this size.

Data Collection and Analysis

The primary sources of data come from National Organizations – such as the NFPA and Joint Commission and personal interviews from staff members. The collection of data from the code books provided a detailed understanding of the requirements that the facility need to meet and how they need to operate. They guided the development of the interview questions that were presented to the interviewed staff. The questions were simple – but opened the table for discussion to get further into the details of the overall operation of the facility.

The interview questions are detailed below

1. How do you control your fire and smoke dampers?
    a. Do you have a firefighter control panel?
    b. If yes, how often is the system tested?
2. Does the facility have a fully engineered smoke control system?
    a. How much has the system changed since the building opened approximately 30 years ago?
3. What systems are tied to the HVAC system?
    a. What happens to the HVAC system when a smoke alarm goes off?
    b. What happens to the HVAC system when a hand-pull alarm goes off?
    c. What happens to the HVAC system when the sprinkler system goes off?
    d. What releases the magnetic door hold opens to seal a smoke zone?
4. What would happen if the fire left one zone and tripped an alarm in another zone?
    a. Does the system recognize the need for a mass evacuation?
5. This facility has 3 large atria within the building – how do you manage a smoke or fire event in these areas?
6. Can you provide any information or feedback of fire/evacuation events in the facility?
7. Research shows that kitchen fires are leading cause of fires.
    a. What type of fire suppression system is in the kitchen in this facility?
    b. Does the kitchen share a HVAC system with any patient care areas?
8. What is unique about this facility and how it responds to a fire/smoke event?

The other two interview questions helped detail the level of experience the interviewee had with this (and other) facilities and the ability to release the information provided in the interview.
Interviews were performed on five (5) separate staff members – each with a different work requirement at the hospital. This allows the data received to have a different, but still correct, answer as each person has varying responsibilities regarding the fire safety and smoke management system.

Interview Panel

- Donald C – shop supervisor – 12 years' experience – 6 at this facility
- Donald S – shop technician – 35 years' experience – 35 at this facility
- Kristian V – shop supervisor – 7 years' experience – 6 at this facility
- Pamela R – administrative manager – 25 years' experience – 15 at this facility
- John E – administrative employee – 11 years' experience – 1 at this facility

Facility HVAC Fire Response

The HVAC system only responds to a fire within the facility when the sprinkler system is activated and the flow switch senses that water is flowing into that zone. This limited response minimizes false alarms to the HVAC system and only requires the change of the system in the most extreme of events. The interviewees state that the smoke alarms trip semi-frequently for things like – burnt toast or popcorn, stubborn patients who smoke in their room, and other minor things that do not warrant a massive change to the system. The smoke sensors are ceiling mounted in all areas of the hospital and are also mounted in the supply and return ducts of the HVAC system. While these sensors may still trigger an audible and visual alarm for the area to be evacuated, they will not warrant a change in the HVAC system. However, the magnetic door releases are tripped in the event of any of these events setting off the alarm. This is due to the simplification of the alarm system and the ease of resetting the doors by just opening them once the alarm is turned off. This also keeps the general public from wandering into the space, regardless of what tripped the alarm. These sensors also report to a central monitoring station monitored by staff that have the ability to respond quickly to verify the magnitude of the response necessary. If the fire department responds to a fire in the facility, there are read-only firefighter panels at all of the main entrances to the hospital. This will provide critical information to the response team when entering the facility, but does not give the responders the ability to control the airflow or sprinklers in the area that is under alarm. (V, Kristian, 2017)

The facility has 87 smoke zones and each one responds depending on its location in proximity to a smoke event. If it is directly adjacent to the area, and on the same floor, the area that is containing the smoke will go into negative pressure and 100% exhaust to outside as to not recycle any of the contaminated air to adjacent areas that share the same air handler. This will 'sandwich' the smoke area with positive pressure while maintaining the negative pressure in the affected area. This is accomplished with smoke dampers that are placed within the ducts of the system. The smoke dampers in this facility are not digital and do not report back anywhere to detail their status of open/close. (V, Kristian, 2017)

Scenario 1: Burnt toast in break room of patient care ward

Smoke detector senses smoke and sets off audible and visual alarm in the ward. Hospital wide announcement for a "Code Red" in specified ward. Safety team and police respond to alarm and determine to cancel the automatic call for the fire department. The alarm is cancelled. Since the HVAC system never changed operation, the smell of burnt toast may spread throughout the ward and could possibly make it to adjacent wards that share the same HVAC system.

Scenario 2: Linen fire in laundry area

Smoke detector senses smoke and sets off audible and visual alarm. Hospital wide announcement for a "Code Red" in specified area. Prior to safety team and police response, fire reaches ~ 165°F and fire sprinkler releases. At this point, the flow switch in the sprinkler system senses flow and the HVAC system serving this area closes the smoke damper and stops the ability for the system to recycle smoke-filled air back from this area back into the system. This area goes into negative pressure by stopping the flow of supply air into the space. Adjacent areas on the same floor will go into positive pressure by reducing the flow of return air from the space. This positive/negative system helps contain the smoke to a specific area. Fire department responds to fire. Once the system can return to normal, the smoke dampers need to be manually reset by the facility staff.

Scenario 3: Deliberate fire in the atrium

Smoke detector senses smoke and sets off audible and visual alarm. Hospital wide announcement for a "Code Red" in specified area. Prior to safety team and police response, fire reaches ~ 165°F and fire sprinkler releases. At this point, the flow switch in the sprinkler system senses flow and the HVAC system serving this area closes the smoke damper and stops the ability for the system to recycle smoke-filled air back from this area back into the system. This area goes into negative pressure and it also releases 4 spring-loaded trap doors at the top of the atrium to push all of the smoke out of the atrium. There are 23 separate zones that are adjacent to the largest atrium that will have to adjust their flow to maintain a positive pressure in their area. Fire department responds to fire. Once the system can return to normal the smoke dampers need to be manually reset by the facility staff.
There are 87 different scenarios in this facility – one for each zone.
When a fire occurs, all other requirements are ignored – temperature, humidity, required airflow, etc. The priority for the facility is that the event is contained to the area that it occurred.

Kitchen Fires

Kitchen fires are another large cause of fires in all facilities with kitchens. As seen in the figure below, cooking equipment makes up 65% of all health care facility fires.
The studied facility has an R-102 Ansul System which consists of a liquid suppression agent that has an activation system that is required to be manually set off with the push of a button.(E, John, 2017) This system is commonly used in many different hospital, restaurant, and hospitality settings. It is tested semi-annually per the Joint Commission requirements which is different than the annual test of the normal fire alarm system. The HVAC system in this area of the facility does not have any direct connection to any patient care areas and if a fire occurred in the kitchen, the patient care areas would not be affected. (C, Donald, 2017)

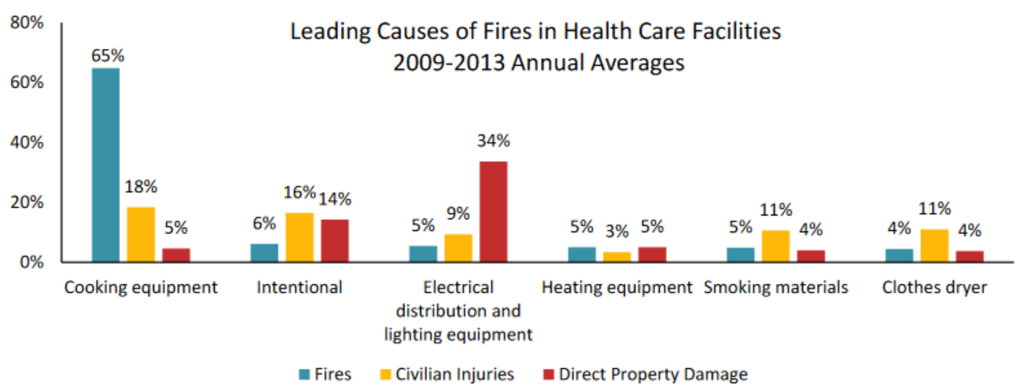

Figure 2 – Leading Cause of Fires in Health Care Facilities (Structure Fires in Health Care Facilities)

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The kitchen HVAC system will only trip into smoke control mode when the sprinklers trip, identical to the rest of the facility. If the Ansul system is fired by a kitchen worker – it will not result in a response from the sprinklers or the HVAC system. Also, the Ansul system is not centrally monitored, meaning that no one will be aware that the system has been set off until a phone call is made to the proper personnel.

Conclusions and Future Research

The most relevant information on this paper came from the interviewees and ends up being mostly facility specific. Each facility should evaluate its system and determine the need for updating or replacement of pieces of their system to provide the most functional, efficient, and safe system for a facility as critical as a hospital.

The NFPA held a discussion in 2015 and 2016 regarding the possibility of increasing smoke compartment size in hospitals from 22,500 square feet to 40,000 square feet. I brought this to the attention of the interviewees and while it would not specifically impact an existing facility, they had definite thoughts about a change like this.(“NFPA 101: Life Safety Code®,” 2015)

The facility Safety Management staff go through a rigorous checklist for each area of the hospital – detailing each area’s need for utilities such as electricity, water, medical oxygen, and many other items. It also details the complexity of moving staff and patients from this area and if the facility has the ability to house these patients at another location in the facility or if they would have to be relocated to an entirely different hospital. (R, Pamela, 2017)

When considering a hospital layout, it is critical to place areas close to each other so the resources are nearby when needed, but also critical to place them far enough apart to make sure that they are not all affected if a single fire event were to occur. If a current facility has adjacent 20,000 SF smoke zones – one being a bank of operating rooms and the other being the intensive care unit that the patients get relocated to after surgery, one of these areas could suffer from a fire event without the other area being affected. If these areas were combined into a single smoke zone – the entire area could be affected in the event of a fire. Obviously, the smoke zones can be made smaller during design of a facility to meet the current need but, in the event of a large remodelling project, this may get overlooked as items like this are not always addressed during the design process. This could cause future problems and a large expense to the facility to break up a large smoke zone into smaller ones.

In addition, the need to upgrade an existing system to a digital system that will report alarms and faults back to a central station is crucial. It is very inefficient for the staff to find a problem with a ward’s air pressure only to find that the smoke damper failed and closed. This damper does not report back to a central monitoring station and has to be found solely by manual labor. Since these dampers are required to be tested every 6 years this type of problem is sometimes not always immediately apparent. Some of the other alarm devices are tested annually or semi-annually and are not as big of a problem to replace faulty devices.(R, Pamela, 2017)

An important topic that currently lacks research is that no research has been done to determine the HVAC system capabilities if two (2) zones, being fed by the same HVAC system, catch on fire at roughly the same time. It is unknown if the system can efficiently exhaust that much air to maintain negative pressure without destroying the air handling unit. Today, studies can be done like this with more ease due to 3D building models and the ability to run simulations on with various scenarios to ensure proper function of the system.

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Optimizing 3D printing path to minimize the formation of weak bonds

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Abstract

3D concrete printing has proven to be a highly favorable construction method in terms of time reduction, cost optimization, architectural flexibility, sustainability, energy use, and others. However, the quality of the final product certainly has a priority over all of these attractive features of the technology. Yet research has given little consideration to investigating the structural integrity of 3D printed concrete structures. Research states that printed structures exhibit sufficient strength as compared to traditionally built structures. Nevertheless, the fact that this strength is sensitive to numerous factors including the machine setup, the printing process, existing conditions (ex. Temperature) and others, should be studied. A major determinant of the reliability and quality of printed structures is the adhesion level between subsequent layers. Poorly adhered concrete surfaces result in weak bonds that in turn reduce rupture strength. The time elapsed between printing successive concrete layers should be bounded to ensure that concrete is flowable enough to adhere to previous layers. For a given concrete mixture design, this time is a function of travel distance and speed. Thus, this research aims at finding the optimum printing path that minimizes the formation of weak bonds without compromising buildability for a given structure and a defined speed. The research employs Discrete Event Simulation to model the printing process for numerous possible travel paths and assess their adequacy by comparing travel time to allowable time limits.

Keywords: 3D concrete printing; delay time; DES; path optimization, weak bonds.

1. Introduction

3D concrete printing is an additive manufacturing technique that allows an automated transformation of 3D design models to actual structures. This is achieved through the deposition of concrete layer after layer [1]. The major contribution of this automated construction technique is that it allows building low-income structures in a timely manner [2]. Moreover, it enables printing any desired sophisticated structure regardless of its architectural complexity. This is due to the ability of adjusting many parameters such as the printer head speed, nozzle selection, speed of concrete flow and concrete properties [3]. Despite these and other advantages, one might question the structural integrity of a member that is constructed by depositing thin layers of concrete as compared to structural members that are monolithically cast. It is of no doubt that the formation of poor bonds or cold joints reduces the tensile strength of a structure. To what extent, however, are poor bonds formed in 3D printed structures?

It might be intuitive to think that joints are unavoidable in a layered system. Yet in reality, tensile strength reduction could be avoided through a proper control of the printing process. The tensile strength between printed concrete layers decreases as the printing time gap between layers increases [4]. In general, the mechanical strength of a layered system decreases and the interface between layers becomes more visually identifiable with the increase in the delay between

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successive layers [5]. The relationship between elapsed time and joint formation is a function of consistency. If the concrete is workable enough, successive concrete layers properly adhere to each other preventing the formation of poor bonds. Consistency decreases with time and thus, time elapsed between successive layer deposition should be limited. Previous results showed that keeping the time gap around 15 minutes results in a high tensile bond strength that could reach 1.5 MPa [4]. Note, nevertheless, that the initial consistency of the mix and the rate of consistency loss affect this time gap.

The most challenging aspect of 3D printing is the presence of trade-offs between various required mix properties. Layers adhesion necessitates an upper limit for the time elapsed between subsequent depositions. Yet an extruded concrete layer must harden enough to support its own weight in addition to the weight of the successive layer. This imposes a lower limit on time delay. This minimum time elapsed between successive layers is dependent on concrete viscosity and is indirectly proportional to the rate at which the yield stress increases [6]. The maximum horizontal velocity, that ensures a minimum time gap below which the binding of successive layers is compromised, can be calculated from the relation between time and thixotropic behavior [7]. Thixotropy means an increase in viscosity when concrete is in a state of rest and a decrease in viscosity when concrete is subjected to a constant shear stress [8]. A faster viscosity loss leads to a smaller minimum time necessary for concrete layers to develop a sufficient strength but also a smaller maximum time necessary for layers to adhere to each other.

Hence, since the formation of poor bonds is time dependent, it is a function of printing speed and printing tool path (i.e. travel path). This implies that a proper selection of speed is contingent on the selected printing path, or for a given speed, the path should be optimized to satisfy the criteria of adhesion as well as buildability. Thus, the aim of this paper is to find the travel path that minimizes the formation of poor bonds between layers. This is achieved by designing a simulation model, particularly a Discrete Event Simulation model, of the printing process of a defined structure given a fixed speed. The model helps determine the range of acceptable travel paths. Then, out of the acceptable paths, the one that results in the lowest printing duration is selected as the optimum tool path. Finally, the model provides a basis for building similar models for different design layouts.

2. Methodology

To achieve the goal of this research, a well-defined methodology was adopted. As a first step, a literature review was conducted to investigate the factors that affect bonds formation between consecutive concrete layers and the relationships between them. After understanding the type of the targeted problem and its elements, Discrete Event Simulation was selected as a modeling technique that fits the research purpose. Discrete Event Simulation is used for systems whose state changes as events occur at discrete time instances. An important assumption states that nothing important takes place between two successive events [9]. The 3D concrete printing process was, hence, modeled as a discrete event system using AnyLogic software. Finally, the obtained results were analyzed and compared against adhesion and buildability criteria. These steps are summarized in Figure 1 below.

Figure 1. Research Plan

A simple design layout was selected for this study to reduce the complexity of the model. It consists of a square area (16 m × 16 m) divided into four equal squares. Although actual design layouts are much more complicated than the adopted design, the latter was deemed to have an adequate level of details for the purpose of building the desired model from scratch. The model can be further expanded and more complex designs can be simulated by following the same logic.

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The simulation of the printing process [10] helps determine the optimal travel paths and any printing gap time if needed. This is achieved by designing the model to give the list of all the possible printing paths. The various printing paths as well as the time it takes to print a complete layer are traced in each simulation run and recorded. Then for each path, the total waiting time of a concrete layer after being casted is compared to an upper and a lower allowable time limits to avoid formation of cold joints while maintaining layer buildability. This gives the range of the acceptable traveling paths that satisfy adhesion and buildability.

3. Model objectives

The global objectives of designing a Discrete Event Simulation model for the 3D concrete printing process subsume the following:

- "Reveal the apparently simple to be complex" [11]. Selecting a path for printing might sound easy. However, once the criteria required for obtaining a printed structure that meets minimum quality standards, the trade-offs that exist between these criteria, and the numerous possible paths that can be taken are determined, this task becomes difficult.
- Identify the optimum travel path that prevents the formation of poor bonds between subsequent concrete layers and, at the same time, allows concrete layers to harden enough to support successive layers.
- Establish a basis for designing future, more complex designs by providing the logic for building such models. These objectives are to be achieved and further analyzed throughout this study.

4. model development

4.1. Conceptual Level

In the proposed model, the 3D concrete printer is modeled as an entity with different states, "Printing" or "Passing". The structure is modeled as consisting of twelve vertical and horizontal links along which concrete must be deposited and eight diagonals along which concrete should not be extruded (Refer to Figure 2). Each link is considered an entity of which the state is either "Printed" or "Not Printed". An event takes place when the printer crosses a link. If the link is "Not printed", the printer state becomes "Printing" and the link becomes "Printed". If the link is "Printed", the state of the printer changes to "Passing".

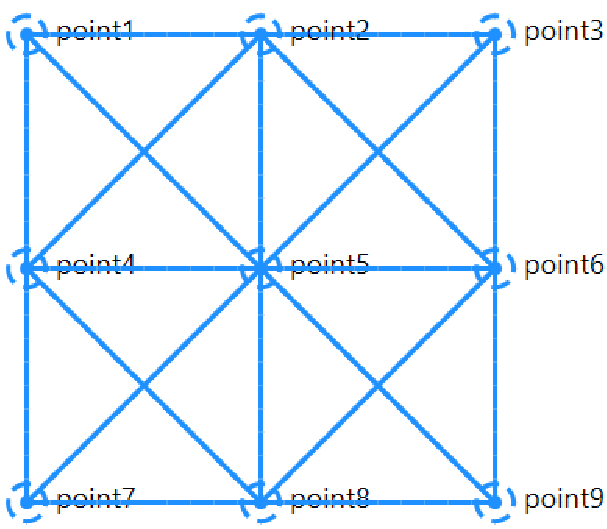

Figure 2. Design Layout

As shown in Figure 2, nine points are marked on the layout. The printer can start at any of the corner points (1, 3, 7, & 9) or the middle point (5). When the printer is at a certain point, it can travel to any one of the neighboring points except for the last point it crossed. As previously mentioned, concrete is to be laid across only twelve links. When all these twelve links are printed, the printing cycle stops, and a new cycle is initiated. The model provides all the possible sequences of traveled links that lead to printing a complete concrete layer.

4.2. Specification Level

Obtaining a sufficiently adhered concrete layers is essential for building structurally sound members. A concrete layer should remain enough workable before a new layer is deposited. Otherwise, concrete layers would become too stiff to intermix with subsequent layers and colds joints would result. This implies that bonding between layers would be weak and, thus, tensile strength would be low, possibly leading to structural failure. Hence, the time elapsed from the point at which the first layer is printed to the point at which the next layer is printed should be limited. An upper limit for this time value is expressed in Equation 1 below.

$$t_{h,max} = \frac{\sqrt{\frac{(\rho g h)^2}{12} + (\frac{2\mu_p V}{h})^2}}{A_{thix}} \quad (1)\ [7]$$

Where:

- V is the horizontal linear velocity.
- ρ is the density of concrete.
- μ_p is the plastic viscosity.
- h is layer thickness.
- g is the gravitational acceleration.
- A_{thix} is the rate at which yield stress increases.

For this study, these terms are given the following values

$$V = 20\ cm/s;\ \rho = 2400\ kg/m^3;\ \mu_p = 50\ Pa.s;\ h = 3\ cm;\ g = 9.81\ N/Kg;\ A_{thix} = 2\ Pa/s$$

The corresponding upper limit is

$$t_{h,max} = \frac{\sqrt{\frac{(2400kg/m^3 \times 9.81N/kg \times 0.03m)^2}{12} + (\frac{2 \times 50Pa.s \times 0.2m/s}{0.03m})^2}}{2Pa/s} = 349\ sec = 5.8\ mins$$

This means that time needed to produce a concrete layer should not exceed 5.8 mins. On the other hand, if concrete layers are too workable, they will not be able to support their own weight or the weight of subsequent layers. This means that buildability will be lost. Thus, the travel rate should not be too high to allow concrete to develop the sufficient strength needed for buildability. The minimum time required to create a new layer is expressed in Equation 2.

$$t_{h,min} = \frac{\rho g h}{\sqrt{3} A_{thix}} \quad (2)\ [7]$$

In this study and given the same previously defined terms' values, the minimum time necessary for producing a concrete layer is

$$t_{h,min} = \frac{2400kg/m^3 \times 9.81N/kg \times 0.03m}{2\sqrt{3}} = 204\ sec = 3.4\ mins$$

Therefore, the time needed to extrude a concrete layer to prevent poor bonds formation while maintaining buildability should be limited between 3.4 and 5.8 mins. Any path of which the printing duration falls outside this range is rejected.

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4.3. Computational Level

At this level, a computational model is developed. Even though the concept seems very simple, Figure 3 below shows how complex the situation actually is. This verifies one of the modeling objectives which consists of revealing the possible complexity of a process that appears to be simple. An explanation for the computational model is provided on the following page.

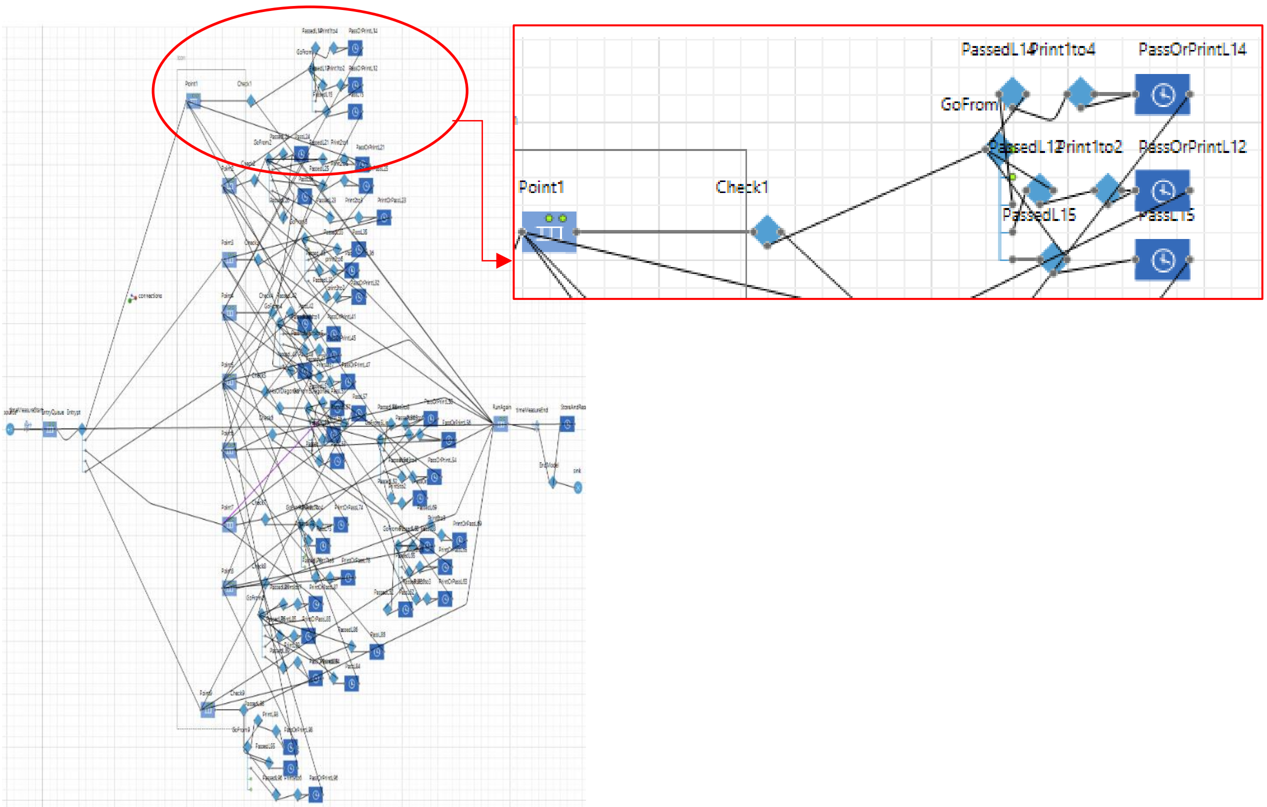

Figure 3: Discrete Event Model using AnyLogic

The printer, which flows through the system, is generated from a source. The printer enters a queue before it moves to one of five points. The choice of the destination point is made random by using selectOutput5 command from AnyLogic library and assigning equal probabilities to different links. Points are modeled as queues and passing/printing links are modeled as delays. The delays are assigned durations computed by dividing the travel distance (i.e. link length) by the horizontal linear velocity. Each time the printer arrives to a certain queue, a certain link is chosen also using selectOutput command and the type of the activity/delay, “Passing” or “Printing”, is determined based on the state of the link, “Printed” or “Not Printed”. Once a total of twelve vertical and horizontal links become printed, everything is restored to their initial conditions and the printer repeats the same process to record a new path. The model is designed to allow the user to set the total numbers of possible paths (runs) needed. Once this number is obtained, the printer is disposed into the sink and the simulation run stops.

5. Simulation Results

5.1. Paths Results

Running the model results in an excel file comprising the printing duration and the path taken for each printing cycle/run. Accepted paths are marked with a green check sign. A sample of the results is illustrated in Table 1. In the results, the links are denoted in a specific format (start,end) to indicate the direction in which the printer is travelling. For instance, L32 indicates that the printer is travelling from point 3 to point 2.

Table 1. Run Results

Run #	Time Take	Path
19	✗ 989.2	L32 ,L25 ,L58 ,L89 ,L96 ,L62 ,L23 ,L35 ,L58 ,L89 ,L95 ,L56 ,L63 ,L32 ,L25 ,L58 ,L87 ,
20	✗ 944.6	L98 ,L85 ,L56 ,L69 ,L98 ,L85 ,L56 ,L63 ,L32 ,L25 ,L56 ,L63 ,L32 ,L21 ,L14 ,L47 ,L78 ,
21	✗ 624.6	L56 ,L69 ,L98 ,L86 ,L69 ,L98 ,L85 ,L56 ,L69 ,L98 ,L87 ,L74 ,L42 ,L23 ,L36 ,L69 ,L98 ,
22	✗ 672.8	L56 ,L63 ,L32 ,L21 ,L15 ,L52 ,L21 ,L14 ,L47 ,L78 ,L89 ,L96 ,L63 ,L35 ,L56 ,L63 ,L32 ,
23	✗ 697.4	L14 ,L47 ,L78 ,L89 ,L95 ,L58 ,L86 ,L63 ,L32 ,L21 ,L15 ,L58 ,L89 ,L96 ,L63 ,L32 ,L21 ,
24	✗ 408.2	L12 ,L23 ,L36 ,L69 ,L98 ,L84 ,L41 ,L12 ,L23 ,L36 ,L69 ,L98 ,L85 ,L52 ,L23 ,L36 ,L65 ,
25	✗ 576.4	L32 ,L21 ,L14 ,L45 ,L52 ,L21 ,L14 ,L47 ,L78 ,L89 ,L96 ,L65 ,L58 ,L87 ,L74 ,L48 ,L89 ,
26	✗ 1245.6	L52 ,L23 ,L36 ,L69 ,L98 ,L85 ,L52 ,L21 ,L14 ,L47 ,L78 ,L85 ,L52 ,L26 ,L65 ,L58 ,L84 ,
27	✗ 832.8	L12 ,L23 ,L35 ,L52 ,L21 ,L14 ,L48 ,L89 ,L96 ,L62 ,L23 ,L36 ,L65 ,L52 ,L21 ,L14 ,L47 ,
28	✓ 296.4	L14 ,L42 ,L25 ,L54 ,L47 ,L78 ,L85 ,L56 ,L69 ,L98 ,L86 ,L63 ,L32 ,L21 ,
29	✗ 556.4	L52 ,L23 ,L36 ,L68 ,L89 ,L96 ,L63 ,L32 ,L21 ,L14 ,L45 ,L52 ,L23 ,L36 ,L65 ,L52 ,L21 ,
30	✗ 528.2	L96 ,L63 ,L32 ,L24 ,L45 ,L52 ,L23 ,L36 ,L69 ,L98 ,L85 ,L56 ,L69 ,L98 ,L87 ,L74 ,L45 ,
31	✗ 909.2	L96 ,L65 ,L52 ,L26 ,L65 ,L52 ,L21 ,L14 ,L48 ,L89 ,L96 ,L65 ,L58 ,L89 ,L96 ,L63 ,L35 ,
32	✗ 732.8	L36 ,L69 ,L98 ,L85 ,L54 ,L47 ,L78 ,L85 ,L56 ,L69 ,L98 ,L87 ,L75 ,L56 ,L69 ,L98 ,L86 ,
33	✗ 597.4	L36 ,L65 ,L59 ,L98 ,L87 ,L75 ,L56 ,L63 ,L32 ,L21 ,L14 ,L48 ,L85 ,L52 ,L24 ,L45 ,L56 ,
34	✗ 804.6	L96 ,L63 ,L32 ,L25 ,L54 ,L41 ,L12 ,L25 ,L54 ,L41 ,L12 ,L23 ,L36 ,L62 ,L25 ,L56 ,L69 ,

The model was run a total of 10,000 times, of which 9,703 paths were not accepted since their printing duration was outside the acceptable time range (3.4 to 5.8 mins). These paths were rejected since their total durations result either in poor bonding between successive layers or in distorted layers' pattern.

297 paths had durations that lie within the acceptable time range. The shortest acceptable path had a time of 4.8 mins (288 sec), and the longest acceptable path had a time of 5.7 mins (344 sec). However, the longest rejected path had a total time of 45 mins (2704 sec). It is important to note that even though this value is not realistic, it shows up in the model since the printer moves randomly across the links. Such behavior can lead to passing the same links several times redundantly. These cases are disregarded anyway since they do not satisfy the requirements. The graph shown in Figure 4 below summarizes the results of the 10,000 runs sorted from the lowest accepted times (grey color) to the largest rejected times (orange color).

Note that for this design and the chosen horizontal velocity, all the paths fulfilled buildability requirement since the lowest duration needed to print a complete layer was 288.2 sec, which is greater than the minimum time for layer reduction (204 sec). Thus, the criticality of a certain criterion related to 3D concrete printing is contingent on the design layout and machine setup. In this study for instance, adhesion criterion is more critical than constructability criterion.

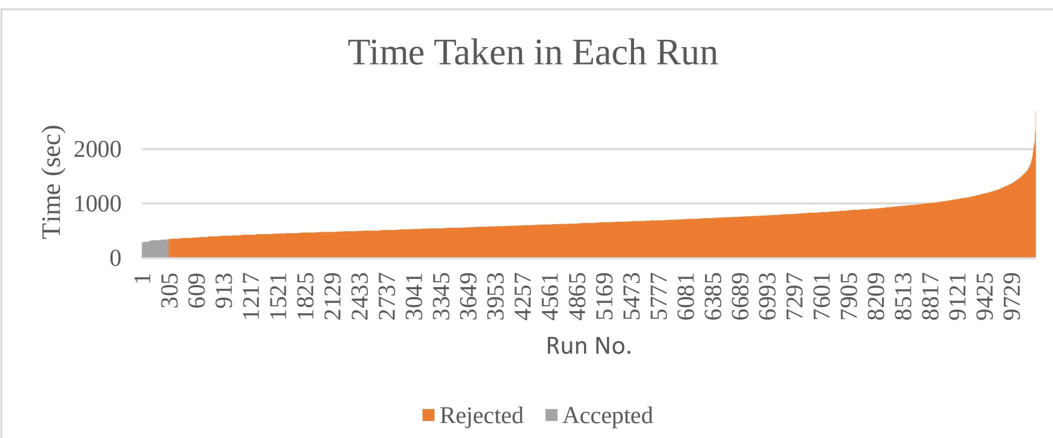

Figure 4. Summary of results

Figure 5 below shows the distribution of the obtained results. The distribution shows that most of the resulting paths do not comply with the accepted time range. It is important to note that this data reflects the results of a relatively simple and symmetrical structure. However, if a more complex structure was modelled, the distribution of the results may be different, and most probably will be more skewed to the right.

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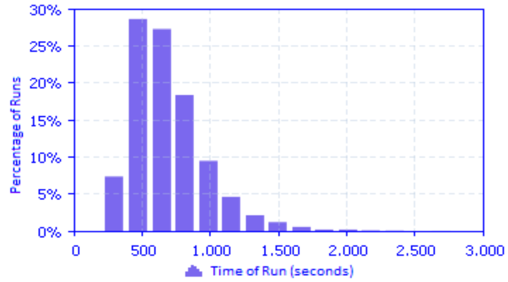

Figure 5: Distribution of Results

5.2. Optimum Paths

Since 297 out of 10,000 paths fall within the acceptable time range, the paths with the shortest duration should be selected to optimize time and cost. Although other paths with longer durations are acceptable in terms of adhesion, they comprise some movements that are deemed unnecessary and wasteful. Hence, they are disregarded. In the obtained results, 13 paths had the shortest time of 4.8 mins. The table below shows these paths in more details.

Table 2. Shortest Paths

Run #	Time Take	Path
2210	288.2	L14 ,L45 ,L56 ,L68 ,L85 ,L52 ,L21 ,L14 ,L47 ,L78 ,L89 ,L96 ,L63 ,L32 ,
2950	288.2	L74 ,L45 ,L56 ,L68 ,L87 ,L74 ,L41 ,L12 ,L23 ,L36 ,L69 ,L98 ,L85 ,L52 ,
371	288.2	L54 ,L47 ,L78 ,L85 ,L52 ,L26 ,L63 ,L32 ,L21 ,L14 ,L45 ,L56 ,L69 ,L98 ,
3069	288.2	L52 ,L21 ,L14 ,L48 ,L87 ,L74 ,L45 ,L56 ,L63 ,L32 ,L25 ,L58 ,L89 ,L96 ,
3751	288.2	L52 ,L26 ,L69 ,L98 ,L87 ,L74 ,L45 ,L56 ,L63 ,L32 ,L21 ,L14 ,L45 ,L58 ,
4147	288.2	L52 ,L21 ,L14 ,L42 ,L23 ,L36 ,L65 ,L58 ,L87 ,L74 ,L45 ,L58 ,L89 ,L96 ,
5126	288.2	L56 ,L69 ,L98 ,L87 ,L74 ,L48 ,L85 ,L56 ,L63 ,L32 ,L21 ,L14 ,L45 ,L52 ,
7100	288.2	L32 ,L25 ,L56 ,L69 ,L98 ,L86 ,L63 ,L32 ,L21 ,L14 ,L47 ,L78 ,L85 ,L54 ,
7522	288.2	L98 ,L87 ,L74 ,L45 ,L56 ,L63 ,L32 ,L26 ,L69 ,L98 ,L85 ,L52 ,L21 ,L14 ,
7763	288.2	L52 ,L21 ,L14 ,L45 ,L58 ,L86 ,L65 ,L52 ,L23 ,L36 ,L69 ,L98 ,L87 ,L74 ,
8119	288.2	L52 ,L21 ,L14 ,L45 ,L58 ,L89 ,L96 ,L65 ,L54 ,L47 ,L78 ,L86 ,L63 ,L32 ,
8136	288.2	L14 ,L45 ,L56 ,L69 ,L98 ,L87 ,L74 ,L41 ,L12 ,L23 ,L36 ,L62 ,L25 ,L58 ,
9809	288.2	L74 ,L41 ,L12 ,L25 ,L54 ,L47 ,L78 ,L85 ,L56 ,L68 ,L89 ,L96 ,L63 ,L32 ,

From these results, it can be observed that all these paths only have one diagonal ‘passing’ link. The results show that most of the paths started from the center point (point 5). It is important to note that the symmetry of the structure used in this study leads to obtaining symmetrical paths with equal printing durations. Were the model run infinitely, all these paths would have resulted, and the model would have been verified. If a more complex structure was modelled and simulated, it is expected that much fewer paths will have the same shortest durations. For a more complex geometry, the model might not even find any acceptable path under the prevailing conditions. In that case, manipulating the printing speed, the extrusion rate, the thickness of concrete layers, the mixture design is deemed necessary.

One of these optimum paths is traced in Figure 6 below. The printer starts at the black node, travels through the black links then through the orange links and stops at the orange node. Note that the printer does not extrude concrete along the dotted lines.

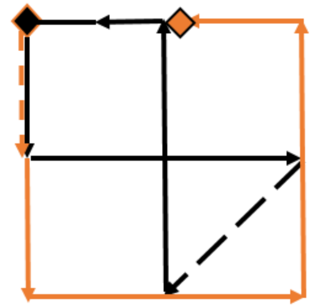

Figure 6. One Optimum Path

6. Conclusion

The formation of cold joints in 3D printed concrete structures and their impact on durability is yet an open research question. This paper aimed at establishing a systematic methodology to optimize 3D printing paths for minimum poor bonds formation. Moreover, a Discrete Event Model was developed using AnyLogic software to simulate the 3D printing of a simple symmetrical structure. The model was run 10,000 times and 297 paths were identified to satisfy a required time range criterion. The time range calculated is dependent on the properties of the concrete mix and the horizontal velocity of the printer. The lower limit of the time range will allow the concrete layers to harden enough to support successive layers while the upper time limit will limit the formation of poor bonds between subsequent concrete layers. In the produced model, all the paths fulfilled the buildability requirement. On the other hand, of the 297 accepted runs, only 13 paths were chosen to have the optimal (shortest) travel distance and time. The data obtained from the simulation, which consisted of the duration and the exact route taken by the printer on each path, can be exported to a spreadsheet for further analysis. The model was built as a proof of concept and should act as a basis for developing new models to optimize 3D printing paths for more complex structures. Following the same logic from the built model, the achieved path optimization will aid in forming more sound and durable concrete structures with the least possible waste. Further experimentation and research should be made to verify and validate the results of the model. This can be done by printing identical 3D concrete structures using different accepted paths obtained from the model and then testing the bond strengths in each one of them. Further research could also focus on producing an Agent Based Model that is more generic and will allow the end user to quickly import a CAD drawing and run the simulation to get the optimized path.

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Potential impact of phase change materials on energy reduction in Army buildings

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Abstract

Buildings account for approximately 40% of energy consumption in the United States with Heating, Ventilation, and Air Conditioning (HVAC). The Army is the largest building owner within the Department of Defense and has the ability to impact the energy consumption within buildings reported in the United States. To date, Army has been making great strides in building new construction and renovation projects to meet high performance sustainable building goals set by the federal government and have further adopted ASHRAE 90.1 and 189.1 standards. With these additional goals of achieving Net Zero Energy, Energy Independence, and Energy Security to ensure continued support of the Army's Mission and maintaining National Security, there is a need to continue to drive further energy reduction within these buildings. Phase Change Materials have been identified as a building material that has potential to impact more energy reduction within our buildings by providing a lightweight thermal energy storage solution that stabilizes temperature swings within buildings. This material, when designed with consideration of local climate and building thermal loads, can support reduced HVAC system sizing needed to meet interior thermal comfort requirements thereby driving greater energy efficiency of buildings.

Keywords: Army; Phase; Materials; Energy; HVAC;

1. Introduction

This research study evaluates the use and impact of phase change materials (PCM) on energy conservation and energy management in building applications for Army facilities. The research involves literature review, survey of professionals (manufacturers, vendors, construction contractors, and engineers) who are involved in the production, specification, or installation of PCMs in building envelopes, and analysis of collected data from buildings on Army installations where PCMs have been installed. The primary goal is to determine what PCMs may be appropriate and life cycle cost effective for Army building applications, including recommendations for installation locations within the building envelope, and appropriate Army facility types and climate zones in the United States. This research is significant as buildings consume approximately 40% of energy used in the world and contribute greatly to greenhouse gas emissions influencing greater changes in the climate. The Army, as the largest owner of building square footage in the Department of Defense, can make a significant impact in the United States' energy consumption through improved energy efficiency of its buildings.

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2. Literature review

According to the U.S. Energy Information Administration, as of 2015 residential and commercial buildings in the United States are consuming 40% of the nation's total energy used [8]. Estimates today project the energy consumption and associated greenhouse gas emissions from buildings will grow an additional 1.8% per year through 2050 [1]. As an industry it is of paramount importance to identify life cycle cost effective and environmentally responsible technologies that can be integrated into new and existing buildings to decrease overall energy use. With a greater focus on interior thermal comfort of occupants and additional heat loads generated by lighting and plug loads in buildings HVAC systems are sized larger and account for a greater percentage of energy consumption within buildings to keep up. The use of PCMs as a passive system integrated into the building structure for minimizing temperature swings inside the building is potentially a life cycle cost effective solution that will allow for reduced HVAC system sizing and their associated energy consumption while meeting the same thermal comfort performance required by owners.

PCMs have been researched for decades in a variety of applications in building systems to reduce energy use through thermal energy storage capability. “PCMs utilize the principle of latent heat thermal storage (LHTS) to absorb energy in large quantities when there is a surplus and releasing it when there is a deficit” [19]. PCMs as thermal storage of latent heat inherently have the ability to store and release large amounts of energy in the process of melting and solidifying (liquid to solid, solid to liquid, etc.) in the process of changing physical states [12]. When the temperature rises during the day the material's chemical bonds will break apart at which point the material's solid state will transition to a liquid state, absorbing heat in this process. This is considered an endothermic process of phase change when heat is absorbed and the material changes to a liquid from solid [19]. As the temperature lowers – typically during the night, the PCM will expel heat previously absorbed and the material will transition back into a solid state, this is referred to as an exothermic process [22]. The phase change cycling PCMs go through as temperatures fluctuate aids in stabilizing indoor temperatures by minimizing swings [2].

3. Types of phase change materials

PCMs for building applications are typically maintained in solid-liquid states and fall into three categories of material types (Figure 1): Organic, Inorganic, and Eutectic. The categories of PCMs are divided further based on the component or compound makeup of the material as shown below in Figure 1. Comprehensive reviews of PCMs have been conducted recently with phase transition temperatures documented by these three categories [7]. Some researchers like Kylili and Fokaides [12] have chosen to categorized the eutectic type PCMs under the respective organic and inorganic categories rather than viewing them as a separate mixture type PCM category.

Of the variety of PCMs available across desired temperature ranges, the most prevalently used PCMs in construction applications have been paraffin waxes, fatty acids, salt hydrates, and eutectic organic/inorganic compounds in the past 30 years. When specifying PCMs for use in buildings envelopes it is necessary to understand the relationship of the PCM temperature and the melting enthalpy (kJ/l) [22]. In 1981, Schröder and Gawron [21] provided a summary of desirable properties required for PCMs to be utilized in buildings. Of particular note, these properties included matching of phase change temperature to the application with regards to climate, location in building and type of system, material stability, and fire safety.

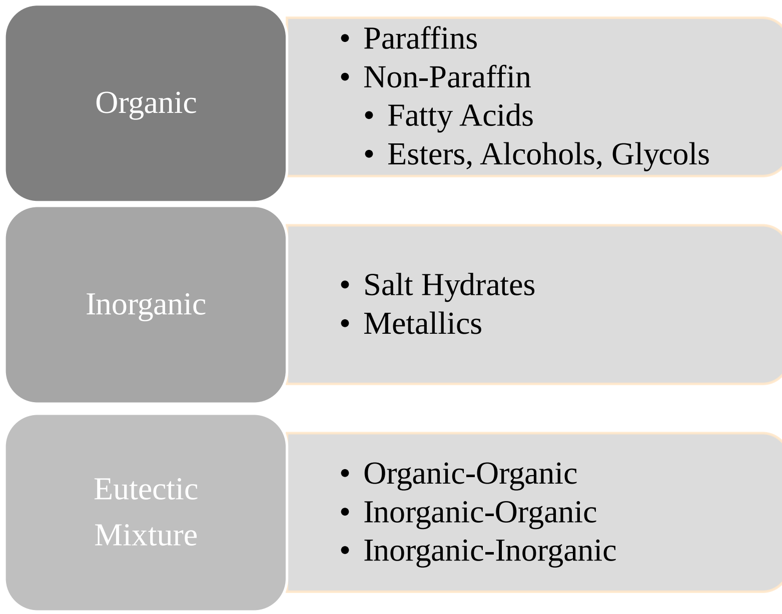

Fig. 1. Categories of phase change materials

4. Building envelopes

Encapsulation of PCMs for building envelope application is generally required for long term use of PCMs to prevent leaking associated with phase transition in these materials [17]. The encapsulating material used should not deteriorate over time or react with the PCM and should account for thermal conductivity and volume changes. Micro- and macro encapsulated PCMs appear to be the two main methods used for building applications. Macro encapsulation of PCMs refers to any type containerization of the material, above the micro- threshold and usually larger than 1cm up to 7.5cm [5], for incorporation into building materials or serving as an independent heat exchanger.

An advantage of microencapsulation type is greater heat exchange surface with the PCM leading to greater opportunity for heat transfer, although lower latent heat storage capacity per unit volume is experienced due to increased encapsulation material. The size of microencapsulated PCMs is small enough that they can be distributed in powder or liquid form added to other construction materials like concrete and gypsum board. This method of encapsulation is considered the most favorable method for integration into building materials [9].

The macro encapsulated containment methods for PCMs are typically flat, tubes, or spheres. A disadvantage of the size of macro encapsulated PCMs has to do with their low thermal conductivity and predisposition to transition phases at the edges first leading to slow energy uptake. This has the potential to cause the system to not discharge overnight completely [9]. Another disadvantage that increases the cost for this type of encapsulation has to do with the required durability of the container material against damage to prevent leakage [20].

As a passive system PCMs applied to building envelopes can influence thermal comfort of interior spaces contributing to reduction of building consumption by HVAC systems [3]. PCMs have been incorporated by manufacturers in a variety of building material applications including: PCM embedded gypsum wallboards, concrete, tiles, mats, windows, coatings and pellets integrated into cellulose insulation. Use of windows incorporating PCMs have been limited due to obstruction of views and translucent appearance. Although window views are desirable, so is daylighting of spaces and Li and Zheng [14] found double glazed windows with PCMs compared to the same windows without PCMs had a 30% lower heat loss and 50% lower solar heat gain. Mat PCMs have been applied as layers in the building envelope typically at the walls and roof.

Walls are found to be the most common portion of the building envelope where PCMs have been incorporated to date with PCM embedded wallboards making this a more favorable approach selected for integration in building

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envelopes. In much of the literature, it is recommended that wallboards are installed on the interior side of the building envelope due to the greater potential for absorbing and releasing heat to the space [22]. A variety of studies were conducted related to wallboard installation [10,12,11,4,18,15]. Additionally, macro encapsulated BioPCM product has been selected for application on interior side of building envelope directly behind standard gypsum wall board in renovations [16].

Concrete enhanced by PCMs has been referred to as thermocrete for being a heat storage medium utilizing an appropriate amount of PCM balanced with either a concrete mix or open-cell cement creating a low-cost storage material that retains structural and thermostatic properties [2]. Microencapsulated PCMs in walls and roofs has been investigated as a coating material on concrete and hollow bricks finding 30% reduction in indoor temperature swings possible in Algerian Climates [6].

Wahid et al. [25] studied paraffin wax based latent heat storage PCMs installed in walls, ceiling and floors identifying significant reduction in temperature fluctuation in the Middle East by storing solar energy for passive solar heating during the daytime hours. Additionally, shape-stabilized PCMs have been studied in floor applications finding rooms with PCM flooring to have a 3-4°F higher temperature than rooms without and a more stabilized temperature range for the room [26]. While in a study of single family homes in San Diego (climate zone 3) and Los Angeles (climate zone 9) integrating microencapsulated PCMs into concrete building envelope materials it was determined greater energy and cost savings could be achieved when applied to south and west walls and PCM temperature matched the desired interior temperature [24]. Biswas & Abhari [4] studied fatty acid/glycerides suspended in HDPE pellets mixed with cellulose in exterior wall insulation practices as well as performed numerical modeling to correspond.

Few energy modeling programs have the ability to simulate accurate level of predictive behavior of PCMs and it may prove challenging for designers to attempt to take advantage of full energy savings and life cycle cost effective integrated design to right size HVAC equipment for true reductions anticipated from thermal control of the envelope with PCMs. PCMs were modeled using EnergyPlus in one study although it is noted that careful analysis should be completed as the accuracy of modeling programs have not been fully validated [23].

Contrary to Gao et al. [7] implication that PCMs are less effective and not recommended in humid and cold climates, Lei, Yang, and Yang [13] studied building envelope installed PCMs in Singapore, a tropical climate, with results of highly effective performance year round. The success was found to be attributed to the placement of PCMs on the exterior side of the building envelope having better results as well as PCMs with a temperature suitable for the application. This discrepancy between sources would indicate there is still research necessary in defining effective applications by climate zone with preferred PCM types and building envelope applications by location.

Kenisarin and Mahkamov [10] proposed additional research areas needed on the ‘optimization of construction elements to provide maximum energy efficiency of building integrated PCM heat storage’ and ‘monitoring and recording of total energy consumed in both the reference and test rooms with PCM heat storage elements over a long period of experiments in order to carry out accurate assessment of the economic viability of application of passive thermal storage system.’

PCMs available in the building industry are diverse with a variety of characteristics to consider in the selection of PCMs for individual building application based on factors of climate zone and weather data, thermal conductivity, and desired interior thermal comfort range. Advantages and disadvantages appear to exist with each category of PCM available and these factors need to be weighed in determining appropriate integration with design of a building and its active systems. Life cycle cost effectiveness of PCMs has not been looked at in detail related to data collected in research as it relates to overall building energy use reduction impact on active systems.

5. Methodology

The qualitative research will implements a questionnaire survey of manufacturers, vendors, and engineers with expertise in phase change materials. This type of qualitative method of research allows for confirmation of personal perceptions and expert knowledge shared in the questionnaire survey of professionals working in the field of PCMs applied to building envelopes. There are multiple interrelated variables involved in this subject (weather data, climate zones, building space utilization, thermal comfort, size/type of HVAC equipment, etc.) found during the literature review process. The qualitative questionnaire survey approach mixed with a quantitative approach to analyze case

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study data will allow for more flexibility in identifying the impact these variables have on the effectiveness of PCMs beyond the limited Army case study sites available.

5.1. Qualitative research

Companies representing manufacturers, vendors, contractors, and engineers that are experienced in the field of PCMs installed in building envelopes either by the production and sale of such materials, or the design and installation of these materials were identified to participate in the survey. As this is an emerging technology in the field of construction that has not been widely used or is widely understood in the Architecture-Engineering-Construction (AEC) industry the pool of qualified potential survey participants in the United States was limited. Surveying a variety of professionals working in this field was selected due to the low number of manufacturers in this field and also to obtain different perspectives on PCM products from all knowledgeable parties involved in successfully integrating these products into buildings throughout the United States in a variety climate zones, as well as, knowledge from some more experienced manufacturers in Europe.

Twenty-one companies representing manufacturers, vendors, and engineers were identified as experienced in the field of PCMs installed in building envelopes on construction projects and were selected for participation in the questionnaire survey. Of the companies requested to respond twelve were identified as PCM manufacturers, six were PCM vendors, and three were engineers who had experience designing for and specifying PCMs in building envelopes.

5.2. Quantitative research

The quantitative research will document two existing case studies of projects on Army installations where phase change materials have been installed in building envelopes. Gas and/or electric utility usage data will be collected from these building sites for conducting analysis of archival data to evaluate the theory of optimized PCM placement in the building envelope for greatest potential effect on thermal comfort of building occupants and energy conservation potential in different climate zones.

Prior to the start of this research study, PCMs had been installed at least one year prior in Army facilities at two known installations located on Sierra Army Depot (Climate Zone: 5B) and Fort Irwin (Climate Zone: 3B). The two locations where PCMs were installed included existing buildings that underwent some level of renovation with goals for improvement in energy performance for the following building types at the respective locations: warehouse and a mix of barracks and offices. All locations had utility meter data available or utilized to conduct some level of performance verification of the building envelope renovation projects prior to the start of this study. Case study projects were selected as a part of this research study to evaluate current performance of buildings after the installation of PCMs in typical Army facility types at installations.

Both projects installed a BioPCM macro encapsulated product on the interior face of the selected insulation added to the building envelope as an energy conservation measure. Army building types represented where PCM was applied and measured include warehouse, administrative office space, and barracks, three common facility types for the Army. Both case studies provided some level of measurement and verification of the energy conservation measures. Methods were similar in that they both included temperature data loggers throughout the buildings and utility consumption rates were monitored to identify realized cost savings during the measurement and verification period to develop final results.

6. Results

Repeated themes were identified in the survey responses around general lack of knowledge related to how PCMs are designed, detailed, and specified as well as installed with some examples given about poor installation by early adopters and underestimated need for credible designs. Lack of knowledge, interest in changing, and forward thinking appears to be the main detractor from using PCMs in buildings with more knowledge needed by engineers, construction contractors, and owners. A second theme that emerged was cost and payback period associated with PCMs in the past with some claims that the costs are coming down on bio-based PCM products making them more attractive. Overall life cycle cost effective determination will be dependent on the success in overall design to achieve a lower total ownership cost based on economies achieved in reduced HVAC system size, reduced interior space, peak load shifting potential, energy use reduction and greater thermal comfort. Additional limitations identified by participants were history of PCMs including petroleum based PCMs that were widely used internationally in past decades, but not in the United States because of fire retardant laws restricting their use. Additionally, salt hydrate type PCMs were discussed as having a short life and marginal efficacy whereas bio-based PCMs are the first commercially available product for building envelopes that are becoming cost effective solutions for buildings in the United States.

Fort Irwin case study used an industry standard approach International Performance Measurement & Verification Protocol Option B to execute the Measurement & Verification (M&V) study which included collection of weather data and additional data points for normalizing the results with the current ambient conditions and results were documented for a full year. The Sierra Army Depot case study only executed measurement and verification for a four-month period, however they took a different approach and compared data between the upgraded warehouse facility and the adjacent warehouse control facility without baseline measurements available like the Fort Irwin case study. Utility meter data was available for both, although the Fort Irwin case study did not have access to the gas meter data for heating periods and had to interpolate the use based on supply and return temperatures measured. Both case studies provided quantified results as a part of the M&V period, however the Sierra Army Depot case study did not include a full year cycle of data to determine performance outcome for all seasons as seen in the Fort Irwin case.

Sierra Army Depot case study data was limited although realized between 33% and 56% reduction in gas utilities during the measured period over the adjacent warehouse control facility during the four-month period. Fort Irwin case study concluded the barracks achieved a 31.6% and the admin building achieved 39.1% energy savings associated with air conditioning over the baseline. The Fort Irwin case study did note times where the air conditioning was left running in the barracks although empty, this could account for the lower energy savings rate than the admin building. Natural gas energy savings during the heating period at Fort Irwin was estimated around 25% on the admin building and 33% on the barracks.

7. Discussion

The most significant impact generated by this study was evaluation of the thermal load generation expected within the structure based on building use to identify ideal locations to include PCM. Army building type recommendations based on high thermal load generation include industrial spaces, child daycare centers, clinics, schools, and offices which emerged from literature review and input from participants.

Climate and weather conditions of the project site should be evaluated to understand extent of passive PCM recharge is possible overnight. Preference indicated by participants in the research was given to Hot-Dry and Mixed-Dry climate zones. It is assumed additional active system intervention would be needed outside of these climate zones considered more ideal for application. It was noted in the research, if large diurnal temperatures are not present to support natural recharge, then assistance by active systems ventilation will need to be considered and designed appropriately to support transition of the PCM.

Integration of HVAC systems for recharging PCMs should include active monitoring and controls with temperature sensors at the PCM locations to trigger ventilation recharging of PCMs when needed. Ideally, for purposes of economizing the design solution and energy savings, the HVAC systems would be reduced in size based on the stabilizing temperature properties and peak load shifting of the PCM.

PCM Manufacturer and Mechanical System Designer should work together to select appropriate melting point and thermal storage capacity of the PCM for the project given the first two considerations above to inform active system design needed. Selection of PCMs should consider proven performance life expectancies given the projected building life. Flammability of paraffin and petroleum based PCMs that are popular and widely used overseas due to high effectiveness should be avoided for United States and Army facility construction as a matter of life safety and compliance with applicable fire codes.

When determining life cycle cost effectiveness of using PCMs, energy cost savings should not be the only factor to justify their use. Total ownership cost reduction must be quantified to include: reduced HVAC system size and cost; associated saved building materials and square footage for smaller mechanical space needed; peak load shifting capability to reduce demand charging by utility providers (if present); thermal comfort and associated energy savings due to temperature stabilization.

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Preliminary structural analysis of a conceptual design for a small-scale erectable lunar habitat

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Abstract

Manned lunar exploration, again, becomes a research focus in recent years, and a number of the leading countries and regions, have announced their own programs. Beyond moon landing, scientists and engineers have started paying more attention on construction techniques for lunar habitation base. This paper introduces a new conceptual structural design of an erectable lunar habitat, using prefabricated building blocks made from the in-situ lunar regolith. The flank wall and foundation of the lunar habitat are fabricated by cubic blocks, among which joggle joint is adopted. Moreover, the roof is erected by arch segments with joggle joint as well and a 2m-thick lunar regolith layer is placed on top to shield the whole structure against the hostile environment. As to the environmental conditions on the Moon (1/6 of the earth gravity, temperature variation of approximate 300K within a lunar day and frequent moonquake), those loads, which would be regarded as irregular on earth, are actually regular for our lunar habitat structure. In order to investigate the behavior of the structure under such extreme loading, a 2D numerical model is established using the finite element software, ABAQUS. In this preliminary study, responses of the habitat structure under static loads of self-weight, overburden pressure, internal air pressure and temperature variation, are simulated. The simulation results give us some requirements on the structural design of this erectable lunar habitat. Several concluding remarks are drawn for both the building block system and the In-Situ Resource Utilization (ISRU) technique of lunar regolith.

Keywords: erectable lunar habitat; conceptual design; finite element; extreme loading; structural analysis;

1. Background

Adjacent to our Earth, Moon is the nearest celestial object, which is also one of the potential energy storehouse for human beings in the future (OuYang, 2005, Badescu, 2012)[1,2]. Helium-3 is a new fuel for nuclear fusion, the reserves of which could serve human beings for more than ten thousand years (ESA, 2018)[3]. In this case, manned lunar exploration, again, becomes a research focus in recent years, and the leading countries and regions, such as the United States, Russia, the European Union and China, have all announced their own Moon-landing programs (Wikipedia, 2018)[4], a series of Mega-Projects (Brookes 2014)[5]. In order to return to Moon for further exploration, habitats for the astronauts are required for long-duration missions on lunar surface. Hence, it is necessary to develop techniques of lunar base construction. For four decades, NASA has been attempting to create a lunar habitat that can support life for an extended period of time (O'Donnell and Malla, 2017)[6].

From 1970s, a number of researchers put their efforts on lunar base study and several structural patterns were proposed. The major patterns are, (1) inflatable structure, (2) rigid structure and (3) mixed structure. For inflatable structure, Nowak *et al*. (1994)[7] designed a modular inflatable structure consisting of thin membranes of composite material integrated with supporting columns and arches. For rigid structure, Lin *et al*. (1989)[8] proposed a

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prefabricated pre-stressed concrete structure with diameter of 120 feet and height of 70 feet. For mixed structure, Aulesa (2000)[9] theoretically proposed a mixed inflatable (transported)-rigid structure (cast basalt, produced in situ), a hemispherical shell structure (dome) covered with a layer of regolith to shelter cosmic radiation.

Due to high transportation costs, ISRU is mandatory in lunar habitat construction (OuYang, 2005, Badescu, 2012)[1,2]. Lunar regolith, the most abundant and available lunar resource, is commonly suggested as a shielding material during the first stages of lunar colonization (Aulesa, 2000)[9]. This paper proposes a new structural pattern of lunar base, *a small-scale erectable lunar habitat*, which is fabricated with erectable lunar regolith blocks and shielded with compacted lunar regolith layer. Moreover, preliminary structural analysis is carried out, including structural responses subject to common static loads as well as the thermal field, which indicates the functional behavior of the lunar structure against the extremely variable temperature. Finally, several material and structural requirements for the lunar regolith blocks are concluded based on the preliminary analysis, and ongoing research work is introduced.

2. Conceptual structural design

The Moon, with a number of similarities, is indeed an alien environment, which is significantly different from our Earth, e.g. as the landform of Moon shown in Fig.1. However, these similarities and differences might also provide us unique opportunities for using the lunar environment and its resources in future space exploration (Aldrin and Eckart, 2006)[10].

Fig. 1. The landform of lunar surface (Aldrin and Eckart, 2006)[10]

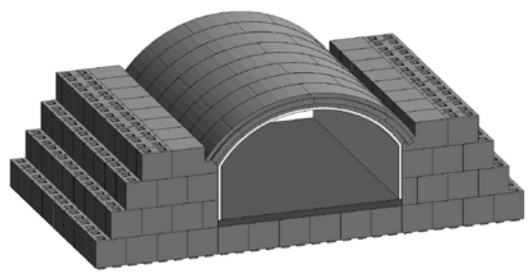
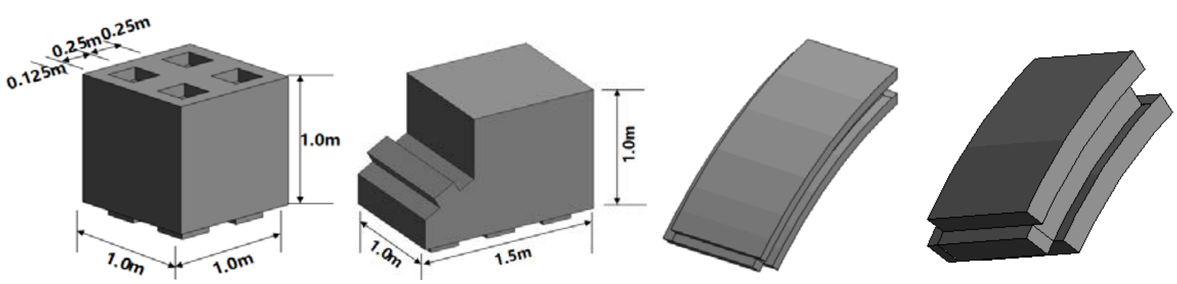


Fig.2. 3D view of the conceptual lunar habitat

This study proposes a new conceptual design of the lunar base, a small-scale erectable lunar habitat. For this conceptual design, a hemispherical arch structure is proposed. It is a prefabricated structure, as shown in Fig.2. The structure composes of a series of standard erectable cubic blocks and arch roof segments, which are made from the in-situ lunar regolith (sintered by microwave or autoclaved). Four types of blocks are designed, i.e. standard block, arch foot block A/B, full arch segment and half arch segment, as shown in Fig.3a, b, c and d, respectively. Standard blocks are erected for the flank wall and the foundation. The width of the flank wall are both 4m, while the internal width of the habitat is about 6m. The arch foot blocks are used to connect the flank wall and the arch roof and also transfer the roof load to the flank wall and foundation. The arch roof consists of three full segments (or two full segments plus two half segments). Total height of the structure could be more than 5.5m. The cross-sectional area of the internal space is about 20m^2 and the length at the longitudinal direction is flexible. In addition, a thick lunar regolith layer is placed on top of the lunar habitat to shield the whole structure against the hostile environment.



(a) (b) (c) (d)

Fig. 3. (a) Standard block; (b) Arch foot block A; (c) Arch roof segment (full); (d) Arch roof segment (half)

As shown in Fig.3, the size of standard block is suggested to follow certain standard modulus, and here we propose the modulus size as 1m. Moreover, the joggle joint between each two standard blocks are Lego style, with four cogging joints. Arch foot blocks (A/B) provide support to the arch roof. Block A is the convex block while B is concave. It is designed to fix the base of the arch roof. The arch roof segments are precast also with convex and concave edges, the shape and connection pattern of which are similar to the lining segments in shield tunneling on Earth. Due to the pattern of stagger-jointed assembling of the arch roof segments, a type of half arch roof segments is used in every other arch. With this design, the erectable structure could be constructed in the longitudinal direction as long as required, and more complex lunar base could also be considered by connecting a number of modularized structural units.

To resist extreme temperature on the Moon and the cosmic radiation, a compacted lunar regolith layer is designed to cover the whole structure. The thickness of the layer is determined based on literature investigation of previous researcher's work. According to Duke's (2006)[11] study, a 2m-thick regolith layer could shelter the lunar base from solar flare radiation, while Vaniman *et al*. (1991)[12] investigated heat flow data from Apollo Moon-landing Project and concluded that an insulating blanket of only about 30cm of regolith is sufficient to dampen out the ~280°K lunar surface temperature fluctuation to ±3°K variation. Jolly *et al*. (1994)[13] suggested the thickness should be between 1m to 4m based on the specific requirements of the lunar environment and the construction factors. Therefore, in the following study, we assume the thickness of the lunar regolith layer is 2.0m.

3. Finite element model

A 2D finite element model is established in the finite element software, ABAQUS, for static analysis for the proposed lunar habitat, as shown in Fig.4. PE4 element (4-node bilinear plain strain quadrilateral) is used to simulate the cross section of the structure. Totally, 3678 meshes are generated. Since the lunar regolith block is closed to concrete on Earth, several basic properties are assumed as follows, the elastic modulus: $3.0*10^4$MPa, poison ratio: 0.3, density: 2500kg/m^3. The considered static loads include the pressure acting on the structure caused by the compacted lunar regolith layer, self-weight of the structure and internal air pressure that maintains when the habitat is in operation.

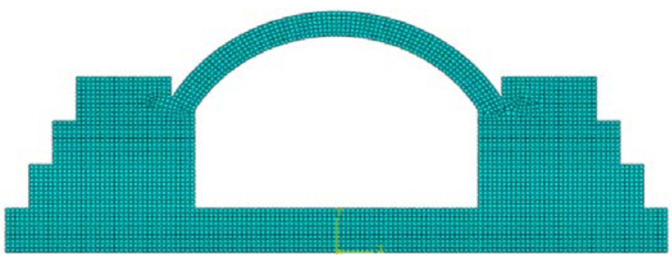


Fig.4. 2D finite element model of the proposed lunar structure

4. Structural behavior under static loads

As to the environmental conditions on the Moon, especially in terms of lunar base construction, it is significantly different from that on Earth. For instance, the gravitational acceleration is only 1/6 of that on Earth; temperature approximately varies 300°K within a lunar day; and moonquake frequently occurs although most of the magnitudes are below 3.0 (Luke *et al*. 2006)[11]. These loads, which are usually regarded as irregular loads in our construction industry on Earth, are actually regular for our lunar habitat structure.

4.1. Overburden pressure induced by the lunar regolith layer

Williams and Jadwick (1980)[14] pointed out that the volume density of lunar regolith varies from 1500kg/m^3 to 1700kg/m^3 at the Moon surface. As to the compacted overlaid regolith layer, the density might depend on the grain size of the lunar regolith and the construction method. Since the layer is to be compacted during the construction, the volume density of the overlaid layer in this study is set as 1740kg/m^3, which is equivalent to dense sand on Earth and will generate a uniform downward pressure of 5.67kPa in the vertical direction (density*thickness*Moon gravitational acceleration).

4.2. Self-weight of the structure

On the other hand, the density of the lunar regolith blocks is set as 2500kg/m^3. Moon gravitational acceleration is one sixth of that on Earth, i.e. 1.63m/s^2, thus the self-weight body force is 4.08kN/m^3.

4.3. Internal air pressure

The lunar habitat is a closed environment with life support system. Therefore, certain internal air pressure is maintained during the base operation. There is no air from the outside to balance the internal air pressure, thus the internal pressure actually becomes an unfavorable load to the proposed structure. Commonly speaking, the best internal pressure is the Earth atmospherical pressure. However, due to safety reasons, it is required that the pressure difference between EVA (extravehicular activity) suit and the internal atmosphere should be as small as possible. Cross *et al*. (2009)[15] compared the cabin pressure of Apollo and Orien driving environment and mentioned that the internal pressure of the lunar habitat that maintains within the range of 34.5kPa to 101.4kPa could provide astronauts with comfortable living environment. Therefore, in this study, the internal pressure of 69kPa is used.

4.4. Model computation

In current study, the preceding three static loads are considered in the model calculation. Moreover, two different working conditions, i.e. 1) construction stage and 2) operation stage, are also separately considered. For the construction stage, the loads includes only the structural self-weight and the overburden pressure induced by the lunar regolith layer, and there is no internal air pressure; for the operation stage, all the three loads apply.

Loading conditions in the model are shown in Fig.5, and model computation shows the following results, 1) principal tensile stress contours; and 2) principal compressive stress contours, as shown in Fig.6 and 7, respectively.

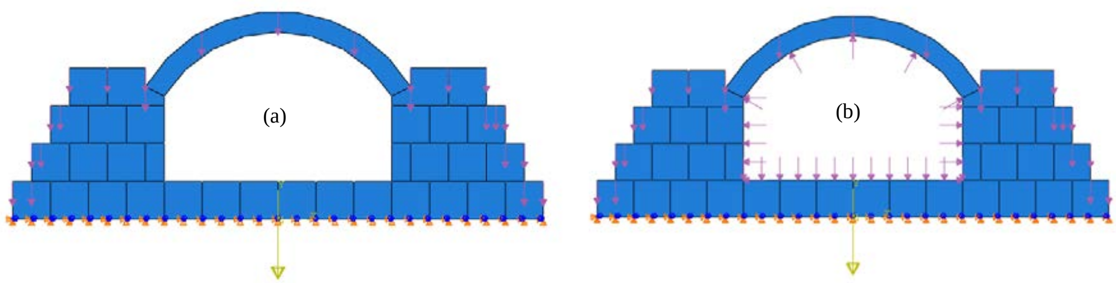


Fig.5. Loading conditions for (a) construction stage and (b) operation stage

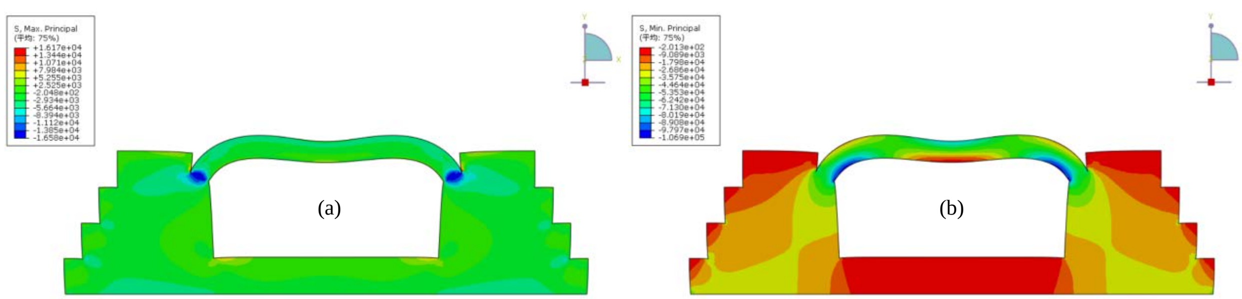


Fig.6. (a) Principal tensile stress and (b) principal compressive stress in construction stage

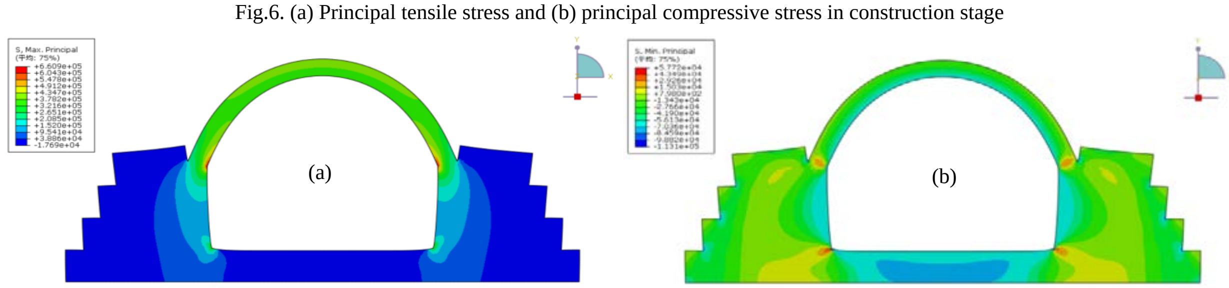


Fig.7. (a) Principal tensile stress and (b) principal compressive stress in operation stage

From the results of model computation as shown in Fig.6 and 7, in construction stage, the maximum principal tensile stress is about 0.02MPa and the maximum principal compressive stress is 0.11MPa; in operation stage, the maximum principal tensile stress is about 0.66MPa and the maximum principal compressive stress is 0.11MPa.

Considering the proposed lunar habitat is a prefabricated structure, the principal tensile stress governs the structural safety. In this case, the maximum principal tensile stress in construction stage is only 0.02MPa, so the structure is relatively safe. However, the structural maximum principal tensile stress in operation stage is up to 0.66MPa, which locates at the connection part between arch roof segment and the arch foot. Prefabricated structure could not bear the tensile force as large as this level, thus we suggest that the internal air pressure should be undertaken by an internal membrane. Despite of this suggestion, we also recommend adding some special structural design to improve tensile strength of the connection.

5. Thermal analysis

A lunar day is equivalent to 28 Earth days with 14 days of sunlight and 14 days of darkness. At the equatorial latitude, the temperature varies from 374°K during the lunar noon to about 120°K at lunar night. The temperature variation decreases as the latitudes increase to the Polar Regions, where it varies from about 160 to 120°K (Mottaghi and Benaroya, 2015)[16].

We assume that the lunar base sits at the lunar South Pole, temperature data of one lunar day at the South Pole is needed for thermal analysis. It is assumed that the temperature drops quickly after the sunset while maintains constant during the night. According to Mottaghi and Benaroya (2015)[16], the temperature variation within a lunar day can be calculated by the following equation,

$$T_m = \begin{cases} 161.607\left[\sin\left(11.4786d + 9.6495\right)^{1/6}\right] & \text{for } 0 < d < 14; \\ 120 \quad \text{for } 14 < d < 28 \end{cases} \tag{1}$$

The variation curve of the temperature is plotted in Fig.8. In the finite element simulation, the thermal analysis of this study considers two extreme conditions, i.e. thermal analysis for the lunar midnight and that for noontime.

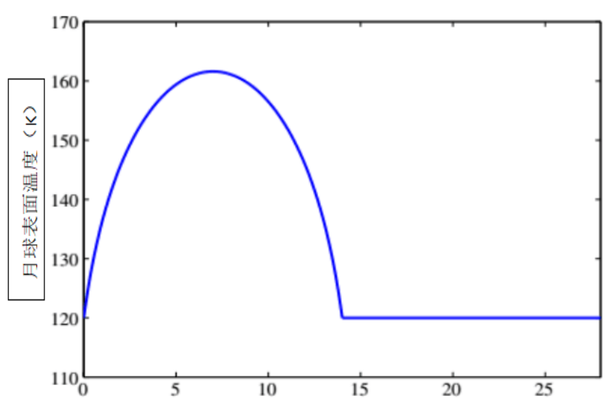


Fig.8. Temperature distribution within a day at the South Pole of the Moon (Mottaghi and Benaroya, 2015)[16]

5.1. Boundary conditions

From Fig.8, the temperature of lunar surface is 120°K. Attributable to the absence of sunlight in the lunar night, the temperature uniformly distributes on the surface of the lunar base structure, which could set as 93°K, the same as the temperature of lunar regolith (Hemingway, et al., 1973)[17]. The boundaries at left, right and bottom are set as heat-insulated boundaries for all working conditions. For lunar noontime, the temperature of lunar surface is set as 161.6°K. Accounting for the sunlight effect, the side exposed under the sun could reach the temperature of 343°K, while the other side is only 105.1°K. Both conditions, the internal temperature maintains constant as 296.2°K (23°C). The thermal boundary conditions are shown in Fig.9 (a) and (b).

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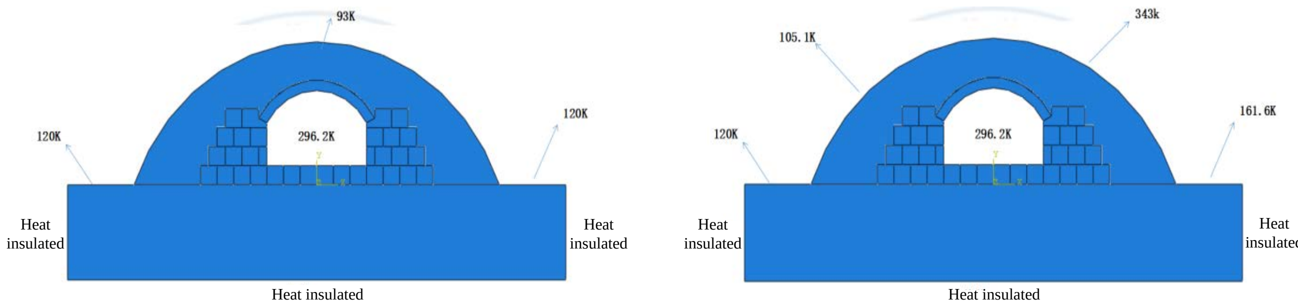


Fig.9. Thermal boundary conditions of the lunar base: (a) midnight; (b) noontime

5.2. Thermodynamic parameters of material

Before thermal analysis, thermodynamic parameters should be determined. The lunar base structure composes of regolith shielding, foundation and the structure. Regolith shielding is a compacted layer of weathered soil from the lunar surface. Heminway et al. (1973)[17] tested samples from Apollo 14, 15 and 16 and found the specific heat capacity and heat conductivity of the lunar regolith with the temperature variation between 90°K and 350°K (see Table 1). Those values in Table 1 are adopted in this study.

Table 1. Thermal parameters of the regolith shielding under different temperatures (Hemingway, et al., 1973)

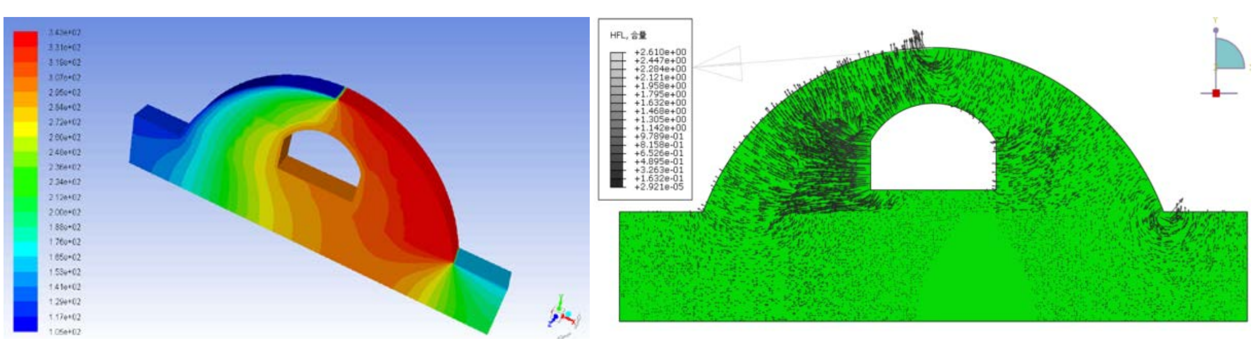
Temperature (°K）	Specific heat capacity (J/kg°K)	Heat conductivity (W/m°K)
100	275.7	0.0007
150	433.9	0.0008
250	672.4	0.0011
300	758.1	0.0014
350	848.9	0.0017

For thermodynamic parameters of lunar ground, based on the data analysis of four groups of Apollo sample, Langseth et al. (1976)[18] estimated the heat conductivity of lunar ground is about 0.9-1.3×10^{-5}W / cm·°K and the specific heat capacity is 670J / kg°K.

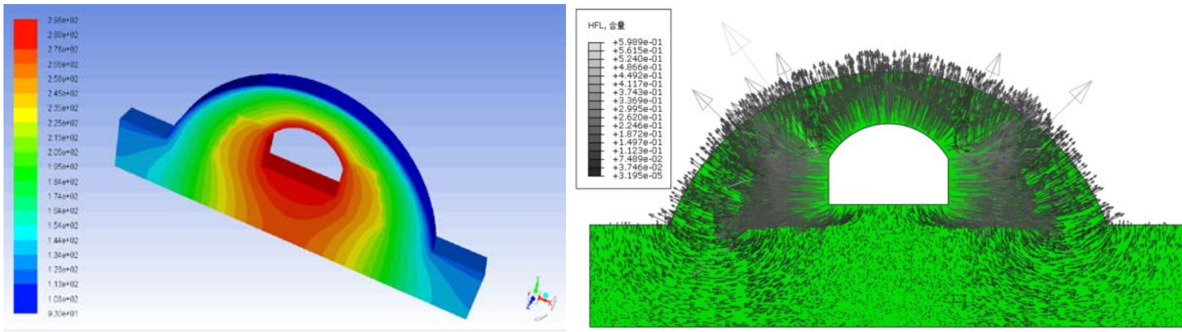
As proposed in foregoing section, the lunar base structure is fabricated by lunar regolith blocks. We assume the thermodynamic parameters are similar to basalt on Earth, thus, the specific heat capacity and heat conductivity of 885J/(kg°K) and 1.65W/m°K are assumed, respectively.

5.3. Analysis of temperature field

With the determination of thermal boundary conditions and the material thermodynamic parameters, numerical model computation gives us the temperature field and heat flow plots in this preliminary study, as shown in Fig.10.



(a) Moon noontime



(b) Lunar midnight

Fig.10. Temperature field distribution and heat flow under two extreme conditions

Fig.10a indicates that, at lunar midnight, the difference between external and internal temperatures is relatively large, and the heat loss for unit length (one meter) of the proposed structure is approximately 22.3W. On the other hand, based on the calculation of the heat flow plots (Fig.10b), the heat loss at noontime for the same length of the structure is about 7.3W, much lower than that of midnight. The heat loss under both these two extreme conditions are still within a low range. These findings from the numerical simulation indicates that the proposed composite lunar habitat structure is relatively competent in heat insulation.

Other effects of the temperature field are investigated in progress, e.g. the extra loads induced by extremely large temperature variation within a lunar day.

6. Conclusion and discussion

To sum up, the following concluding remarks are drawn from this study.

(1) A new conceptual structural design of an erectable lunar habitat is proposed. According to the design, the main structure is fabricated in place by using erectable lunar regolith blocks as building material. In addition, a compacted lunar regolith layer with thickness of 2.0m is placed on top to shield the whole structure against the hostile lunar environment.

(2) Based on the principle of structural design, the major loads the lunar habitat structure may encounter on Moon should be considered as regular loads, although they are normally regarded as irregular loads if it was on Earth.

(3) Considering three static loads, 2D numerical model has simulated the structural responses. The results suggests that, the proposed lunar habitat structure is relatively safe on compressive strength, but the tensile strength needs to be enhanced, especially the parts of the arch foot and the foundation fabricated by cubic blocks. A strong internal membrane is suggested to bear most of the tensile stress induced by the internal atmosphere.

(4) Temperature variation is also an unfavorable environmental condition. With some assumptions, numerical simulation shows the composite structure (structure plus shielding layer) is relatively competent with respect to heat insulation.

These are the four major conclusions in the preliminary analysis while the entire study is still moving on. Several groups are working in parallel for different aspects, including different structural patterns, innovative construction materials, construction equipment and techniques. In terms of structural part, thermal load and dynamic moonquake load are to be considered in the subsequent numerical modeling. On the other hand, structural testing for the model lunar regolith blocks, theoretical analysis for different structural patterns and physical modeling of the structure are planned.

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Social Housing to nZEB - Portuguese Context

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Abstract

Abstract — In the 80's and 90's, the various Portuguese Governments set the goal of rehousing the majority of the low-income families without a proper house, through a program to build Social Housing. Municipalities assumed the role and developed the solutions to meet the needs. The necessities defined priorities, efforts were directed to quantity rather than quality: 120,000 apartments distributed by 24,500 buildings, in 25 years. Designed in-house or contracted out with a conventional approach and a limited budget, around 500 euros/m^2. The construction was outsourced and hasty, due to time constraints.
Although the construction were common, in technology and design solutions, some architectural prizes, National and International, were given to authorial projects. These became symbols of the progressive Portugal Architectural Heritage and of the success of the Portuguese Social Experience, recognized as architectural points of interest, for tourist and specialists.
As time goes by, maintenance falls short and requires critical conservation, tenants demand rehabilitation and renovation, mostly to situations related to the loss of comfort and quality, associated with water damages in the constructive solutions.
The research regarded the latest European Union policies, on GHG emissions and energy consumption reductions in new building design, to pursue the nZEB's, "nearly Zero Energy Building(s)" concept. By developing a low-cost building renovation founded on new constructive solutions to actualize the envelopes' response: decreasing maintenance's needs and expenses, increasing user comfort while aiming the reimbursement of the investment period. Based on the "Renovation or Rehabilitation — Decisive Gains (RoR-DG)," (Nuno D. Cortiços) benefits were accounted considering achieved savings minus investment: relying on the system's performance, as rated by the key indicators of "Facilities Maintenance Management Model" (Igal M. Sohet and Sarel Lavy). This approach was applied to measure the impact of the first Eco-Neighborhood, applied to a Lisbon social housing park (Bairro da Boavista, Monsanto). Although the Program's positive achievements, the results show a low impact on efficiency. For the future actions it is advisable an overall thermal reinforcement, follow-up measures, additional financial support, and the tenants' commitment.

Keywords: social housing, building performance; building maintenance; building renovation; facility management; properties managers

1. Introduction

The research aims to present the gains of the first renovation Program, Eco-Neighborhoods Environment+ - For an Integrated Model on Sustainable Innovation,'[1], a nZEB's, "nearly Zero Energy Building(s)" design concept, applied on a social housing park in Lisbon, Portugal, built between 1988 and 1996: "Bairro da Boavista".

The development of a building's low-cost renovation plan, founded on new constructive solutions, improves the envelopes' response, allows the decrease of maintenance's needs and expenses, and the increase of user's comfort while aiming the investment period reimbursement. Based on the "Renovation or Rehabilitation — Decisive Gains (RoR-DG)," (Nuno D. Cortiços) benefits were accounted considering achieved savings minus investment: relying on

[1] Free translation from the original, "Eco-Bairro Boavista Ambiente+ Um Modelo Integrado de Inovação Sustentável."

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the system's performance, as rated by the key indicators of "Facilities Maintenance Management Model" (Igal M. Sohet and Sarel Lavy) [1][2]. The Program defined guidelines to update the envelope systems to meet the contemporary requirements outlined for nZEB, equal to those required for new buildings in the European Union territory.

After the Paris Agreement, regions and territories went fast-forward to fulfill the committed objectives. The European Union (EU) defined two directives. One generic, "Energy Efficiency Directive (2012)" to help reach a 20% energy efficiency target by 2020, later revised to 40% for 2030 (2016) [3]. And, one specific for buildings, "Energy Performance of Buildings Directive (2016)" with the goal to cut CO_2 emissions by at least 40% by 2030 [4]. The latter puts the energy efficiency in first plan and supports the building's renovation, on a cost-efficient approach.

In the 28 EU countries, in 2016, the residential sector consumed 25,71% of all energy[2], were 6,27% in electricity

Table 1. Final Energy Consumption in Households by Fuel (%) [4][5]

Energy Consumption by Fuel	*Portugal*	*EU - 28 countries*
Electrical	42,3	24,4
Renewable	31,1	15,9
Petroleum Products	16,3	11,6
Gas	9,6	36,9
Solid Fuels	0,0	3,3
Derived Heat	0,0	7,8

consumed for space and water heating, plus other electrical appliances and devices by households. In Portugal, due to climate characteristics and households' social behavior, in that same year, energy consumption ascended to 16,27%[3], in which 6,99% of electricity, as defined above. [5][6] The Green House Emissions (GHG), represented 15% in the EU; and 7% in Portugal: explained by the renewable investment policies in the latter, as Table 1.

1.1. *Question*

In the 1980 and 1990, several Portuguese Governments set the goal of rehousing the majority of low-income families without a proper house, mostly residentes of slums, through the implementation of a program to build social housing. The municipalities assumed the implementation and development solutions to meet the needs. Directing the efforts to quantity in detriment of quality: 120,000 apartments spread over 24,500 buildings, in 25 years. Several projects, designed in-house or outsourced, with a common approach: 500 Euros/m^2, maximum value. Construction was outsourced and hasty, due to time constraints. This legacy is now outdated in energy efficiency, according to latest EU directives; and lacks on maintenance, just to sustain the initial building performance.

In Lisbon, a company, "Gestão do Arrendamento da Habitação Municipal de Lisboa, E.M., S.A" (GEBALIS), manages social housing: 22,949 apartments (plus 1,387 stores) in 5,849 buildings, with 1,211 elevators, distributed over 2,023 lots, in 66 public housing blocks, and 91,500 m^2 parking area.[4]

Based on the analysis of the available data, social housing, in Lisbon, occupies around 2.2 million of building square meters, that, if multiplied by 2.6 meters ceiling-high (plus 10%), results in 2.5 million[5] of façades' square meters. Regulations enforce that the surface of the windows corresponds to, at least, 10% of the interior floor area — the budget control is, as a rule, ensured by the minimum requirements defined in the legislation — resulting in 468,750 m^2 of transparent surfaces. Thus, the social housing tends to 81.25% of opaque façades and 18.75% non-opaque.

The expenditure on social housing, to build or to maintain the building stock, reaches 2.20% (76,194.06 MEUR) in the EU, but in Portugal barely surpasses 0,01% (5.34 MEUR), 2013 values [5].

[2] Households, in EU 28 countries, used 52,1% of natural gas and oils derivates as main energy source for space heating, 2016 (Eurostat).
[3] Households, in Portugal, used 27,7% of natural gas and oils derivates as main energy source for space heating, 2016 (Eurostat).
[4] Data shared on 2015 annual report, "Plano de Atividades e Orçamento de 2015 - Gebalis".
[5] Based on data presented on Statistics Portugal, "Caracterização da Habitação Social em Portugal", published July 9, 2010.

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The average rental income, as published in the GEBALIS' 2015 Annual Report, is € 78/dwelling/month, and the average requirement for building renovation amounts to € 500/dwelling [8]. In 2009, due to the underperformance conditions, the Government defined a 144 MEUR investment plan (around € 500/house), labeled "Integrated Program of Management and Requalification to the Municipal Housing,"[6] to renovate the stock, to start in 2011 until 2020. [9] However, due to recent Portuguese crisis, the plan was suspended and the building stock's condition is now far worse than 2008. As the country emerges from the crisis, it is urgent to resume to the European commitment made by Portugal: to reduce energy consumption in 20% by 2020 [10], although it has been revised to 30% [11]. The Commitment goals apply only to private housing, through the "Building Energy Certification System (SCE)"[7]; although the public buildings are under strict regulations, they only consider government buildings, not including the local administration properties, responsible for social housing's.

The Portuguese government, through the Lisbon Regional Operational Program Authority (2014-2020), submitted a 50 MEUR plan to EU funds (ERDF - European Regional Development Fund), to renovate social housing stock: by growing in efficiency and lowering energy consumption and GHG emissions. Focusing on the thermal insulation of the envelope, the façades and shutter boxes; replacing windows with thermal-break frames, double glazed glass and new blinds; solar thermal collectors for water heating; and costs related with investment planning. [12] Nevertheless, Lisbon region (city include) is considered a developed area, therefore has to support 50% of the entire plan.

Although 50% of social housing stock is less than 20 years, the anomalies are significant and recurrent, especially in the envelope, with water infiltrations in roofs and façades, which also accumulate air-gaps problems, and extensive fractures [9]: with evident contribution to thermal exchanges. In older neighborhoods, the walls of the façades are double-layer finished masonry with cement plaster with 3 cm of insulation (expanded polystyrene boards), thermal insulation according to the current requirements. The absence of proper maintenance of the first envelope barrier, the paint film, impairs the thermal performance, raising the humidity levels.

Portuguese social housing does not use centralized heating or cooling systems; the tenants tend to suppress the needs with the use of individual boilers without condensation (for hot water). Natural gas, e.g. bottles of propane, is the main source of energy for heating water and cooking. Electricity is consumed in individual heaters, lighting and household appliances in general. [14]

1.2. *Background*

Housing promoted by governmental entities is commonly referred as 'public' or 'social,' aimed for a population characterized by low-incomes. The latter also includes minorities and seniors, in considerable numbers, and individuals living on social subsidies. The social housing urbanizations have high-density and a large number of housing units per building; all in small habitation areas with low accommodations availability.

Aging and the lack of maintenance promote a number of problems, especially with regard to indoor quality (from the user's perspective), deterioration of thermal conditions and promotion of moisture accumulation: resulting in the absence of proper thermal comfort and ventilation, adding cigarette smoking residues, pests, and the presence of fungi. The houses often show the presence of water damages, due to the ruptures on impermeables barriers, on roofs and, more often, in flat designs but, also, through the gasket seals in the windows frames; weakening the health of families. Programs on building systems renovation or retrofitting can solve the problems described and enable EU, such as nZEBs, to bem met. [15]

The EU is committed, to comply with the Paris Agreement, to decrease 80 to 95% of GHG derived from the building sector. The thermal renewal of today, of the entire housing stock, is not significative, is between 1-2%. [16]

EU directives imposed the requirement for renovation of the building, so municipalities, as property owners, designed and implemented Eco-neighborhoods programs to fulfill national commitments, in terms of energy-savings and reduction of GHG. The awareness of the residentes, for these problems, is also essential, especially the most vulnerable citizens. [17]

Quality data on building's renovation is an accurate and fundamental tool for achieving the overall efficiency objectives, as it involves property owners, managers, and tenants; and, when applied to investments, can ensure a revenue of unquestionable value, to all parts. [18]

[6] A free translation from the original, "Programa Integrado de Gestão e Requalificação dos Bairros Municipais."
[7] A free translation from the original, "Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior nos Edifícios (SCE)."

Volatile policies, short-term regulations', shared funding effort (as EU fund programs in Lisbon Region), permanent economic loss (tenant's rent per reactive maintenance expenditure), long-term strategies lacking on implementation and complex technical development contribute to a poor systems' performance, even lower than initially achieved. [18]

The renovation of building stock can be efficient if an integrated methodology is used, as the Sustainability Rating Systems (BRS), establishing the reduction and reuse of resources, environmental protection measures, decreasing residues: applying a life-cycle cost control with focus on the overall quality and sustainability, resulting in GHG reduction. [19][20]

Local climate should, above all, guide the approach to implement energy savings policies. In a temperate climate, such as in the south of Europe, the buildings' renovation design must maximize the efficiency and speed the investment return. [21]

Recent literature focus on the importance of the relationship between property managers and tenants, pointing of energy efficiency active measures, mainly, managing consumptions; also, through the implementation of educational programs, assuming technical and social-economic strategies. [22][23] The approach must admit a longer time-frame to gather tangible results [24]; relating users' comfort with energy savings, and for the household financial health [23].

Low-income, basic education or senior-age tenants tend to resist emerging technologies, unless earnings are direct and immediate, on their experience of comfort, and related costs. Moreover, energy efficiency strategies tend to fail if require daily interaction, due to the lack of immediate benefits. On the property management viewpoint, it is possible to ensure renovation outcomes, performance and constancy, but only in the long-term. To solve the problem, researchers and technical studies emphasize the tenants' behaviors and routines to design the renovation strategies, establishing measures, and tools to promote the objectives. [25]

The social housing is a non-profit solution (or a common answer) for dealing with the lack of housing for the less fortunate and more vulnerable citizens. The idea of addressing comfort and energy sustainability, on the public building stock, through today's technologies, depends on governments and external program's capacity; tenant's; economic stability; safety conscience; continuing service and support; and community and social services engagement. At the same time, the building stock renovation helps to promote community development and understand the proper way to engage it in the global problems. [26] [27]

Envelopes' renovation strategies have proven to solve uncontrolled losses and gains on social housing buildings, even without the direct contribution of household; only by accounting the external wall insulation is achievable, in theory, up to 11% in energy savings and cutting 8% of GHG, as presented by a survey on social housing in Nottinghamshire, UK. [28]

Considering the traditional external wall solutions, the thermal transmission coefficient, constructed during the 80 and 90's, in Portugal, is between 0,51 to 1,1 W/m^2.K maximum. The typical solution resorts to light-brick in double layer, finished with mortar on the exposed surfaces, the wall cavity with or without thermal isolation board. To reduce those values and pursuit the nZEB concept, 15 kW/m^2.year, the solutions cost tends to be above 10% when compared with the market current solution; therefore, the investment only justifies if guarantees the return before the lifespan term. But, if renovation's cost surpasses 50% current market value, is impossible to defend positive results. [29]

1.3. *Possible Approach*

The goal is to analyze the viability and the outcome of the first Eco-neighborhood, made in Lisbon, as an example for future projects. The Lisbon Municipality designed a Program to renovate the "Bairro da Boavista - Masonry Area," in Monsanto, applied from 2012 to 2015, to retrofit selected buildings, through improvement on façades: on the walls, adding an external lime aggregate above a cork layer (30mm)[8]; and, on windows, replacing the simple aluminum frames of single glass by a PVC frame with double glazed window[9]. The Eco-neighborhood Program, submitted in 2009, approved and funded in 2011 by EU programs, divided: 65% by QREN[10] – Lisbon Operational Program and FEDER[11] - European Fund for Regional Development, and 35% by the Lisbon Municipality. The Program was organized into four phases and was under the Municipally Agency for Sustainability (Lisboa E-Nova) and the Engineering National Laboratory (LNEC)[12], technical support.

[8] Walls commercial solution, "Secil SecilVit CORK."
[9] Windows commercial solution, "Caixiave PVC."
[10] The "QREN - Quadro de Referência Estratégico Nacional" is a national strategy for the implementation of the Community policy on economic and social cohesion in Portugal in the period 2007-2013.
[11] "Fundo Europeu de Desenvolvimento Regional"
[12] "Laboratório Nacional de Engenharia Civil"

Although all literature produced on the Program guidelines, mainly to advertise measures, no data, results or conclusions were learned: on the Program or on tenant perspectives or other. The outcome remains uncertain. To account specific gains and to guide future programs it is imperative to understand the work produced. At the same time, it is aimed, through testing and improving, the development of the “Renovation or Rehabilitation — Decisive Gains" (RoR-DG)”: a method to understand the real impact of renovation operations. [31][32].

Table 2. “Bairro da Boavista”, Lisbon, under renovation Program.

Renovated Building Systems	Before (1988-96) [30]	After (2014)	Diferencial
Walls	1,1 W/m².ºC	0,60 W/m².ºC	0,50 W/m².ºC
Windows	4,8 W/m².ºC	2,7 W/m².ºC	2,10 W/m².ºC

1.4. Manuscript Structure

The paper begins by addressing the problem, the social housing renovation in the EU's perspective of existing building stock. The background exposes the approach of the principal published works, in the last three years (as below quoted), through conclusions analysis. By explaining the problem, on public and tenant’s perspective, is possible to establish the path adjust the RoR-DG to social housing specifications. In the end, by filling the method tables; results and findings get assessed, and the research presents the conclusions; by exposing the Program omissions and advising the future strategies.

2. Methodology

Social housing, in the city of Lisbon, provides residence to 75.000 citizens [30]; therefore, efforts to gain energy-efficiency must coordinate the actives and passive systems.

In the chosen sample/stock, the tenants control the indoor comfort temperature, therefore, is excluded from this approach, due to close relation to the solar exposure and other externalities (metabolism, occupation, acclimatization unities, induced ventilation, humidity presence, et cetera). Instead of analyzing the behavior data, its opted the National Legislation on buildings' thermal comfort (3rd generation), Decree-Law 118/2013 of August 20, 2013. That establishes 20ºC for the cold season and 25ºC for the hot season, setting the quantities in Celsius degrees needed to proper climatize a building in Monsanto, Lisbon. Data collected through photographs of the renovation work, on-site visual inspection and measurements, and designs, all confirmed by Portuguese construction codes (LNEC) [31].

2.1. Passive Building Systems - Investments

Two passive systems received renovation, façades wall and external windows. On façade walls, by applying the initial thermal transference values is possible to calculate the gains, when putting beside the renovation performance. The RoR-DG, on Table 3 and 4, exposes the impact of the Program in the years to come, on decennial periods (10, 20 and 30).

The method works by assessing the building systems to determine the main key-indicators. The “Building Performance Indicator” (BPI) defines the condition of the envelope systems, by multiplying the system’s weight on building's type [1][2][34], due to lack of maintenance, since the construction’s conclusion, it is classified as a “poor or dangerous performance condition”, translated by the visible cracks that promote leakages and the air gaps. The same happens in the original windows, with the waterproof barrier collapse and the lack of air tightness, due to misalignments derived from the manoeuvres. The “Decision Impact” (DI) is the expenditure, in percentage, to maintain the existing solution performance [34].

To understand the amount of energy saved, on intervened systems, the whole is reduced in one square meter: the two solutions have a “Wal-to-Windows Ratio” of 81,25% for opaque and 18,75% for transparency [35]. The ratio derives from the pavement areas, as requested for social housing, then façades areas and windows' occupancy.

The section "Investments per m^2" exposed the renovation costs, as shown. The "Condition Factor (percentage)" accounts the operational difficulties for workers and necessary technical skills, equipment, tools, materials, and security. "Renovation Solution Maintenance (Eur) (Cype)" means the renovation value expected for the next 10 years accordingly with Cype[13]. The "Subtotal" accounts all renovation costs on a square meter in the first 10 years (period).

Table 3 — RoR-DG — Investment Analyses

Year	Region	Period	Renovation or Rehabilitation — Decisive Gains - Investment Analyses				
2014	Lisbon	10	Envelope				Total
		Systems (BPI<0.80)	Walls	Roofs	Windows	Shaders	
		BPI [1][2]/System	0,33				0,33
		Decision Impact [34]	0,99848%				0,99848%
		Wall-to-Window Ratio [35]	81,25%		18,75%		100%
		Maintenance (previous year)	0,00 €				0,00 €
Investment per m^2							
		Preparation (Eur/m^2)	3,96 €		2,93 €		6,89 €
		Renovation (Eur/m^2)	47,76 €		492,05 €		539,81 €
		Condition Factor (%)	25,00%		10,00%		0,35 €
		Renovation Solution Maintenance (Eur) (Cype)	2,02 €		44,28 €		46,30 €
		Interest Rate					
		Interest Period (years)					
		Subtotal*WWR	54,17 €		110,39 €		784,35 €

Due to the Program financial nature, no interests were accounted.

The section "Savings per m^2" exposes the renovation gains, as presented. Those obtained through the reduction of thermal losses and savings with maintenance costs by multiplying the amount Celsius degrees needed to climatize the indoor spaces, in the city of Lisbon, with the "Local Energy Price (Eur/kWh)," when renovated systems values are confronted with the initials. The "Subtotal*WWR," on investments and savings, presents the values in decennials periods on a façade square meter; if multiplied by the total area, it would translate the absolute amounts.

2.2. Active Building Systems and Equipment

The appliance makers advertise the energy efficiency of active systems, by appealing to consumers to acquire "A++" labeled products, current or based on heat-pump technology. Medium income families, slowly recur to new technologies to cut electric consumption. But those, who live in social housing, by definition, do not have means to assume that role.

3. Results and Discussion

The results, at the end of Table 4, do not showcase significative reasons for all investments made versus savings, when the balance exposes the financial outcome. More, the improvements never, on any decennial period, reach a positive value. And even worse, when the focus is on the windows' systems; the investment is never recovered, due to

[13] © CYPE Ingenieros, S.A. - Software for Architecture, Engineering and Construction, 2017. Available: http://www.cype.com/en/cype/

the high prices of the framing and glass technology, with limited life expectancy, around the 30 years mark, and elevated maintenance expenditure. Even by accounting GHG emissions saved, as 45 to 50/t [36].[14]

The overall value almost breakeven before the 30 year mark, but the windows' systems, with a high degradation rate, invert the results cycle. The accountable outcomes do not consider all gains, as the immediate comfort and households' health on a long-term (and general). Although the energy savings did not pay back the investments, the Program points in the right direction in the pursuit of the nZEB concept.

The initial Program was more extensive and ambitious, by considering other measures as sun collectors, photovoltaic panels, and wind power towers, on a near communal sports field, but due to economics constraints, during development, none of those was installed. Something similar occurred to the passive solutions. The façade wall renovation went from the initial 40,000 m2 to 18,000 m2 [37], and the windows replacement, from initial 3,000 m2 to

Table 4 — RoR-DG — Savings Analyses

Local Energy Price (Eur/kWh)	0,17 €		Envelope		Solar Radiation (90º wide)	
$Q_{tr,i\&v} = 0,024.GD.H_{tr,i\&v}$	Heat		25,68 kWh/m2		South	
	Cooling		9,66 kWh/m2			
	Building Systems	Walls	Roofs	Windows	Shaders	Total
		Renovation over Rehabilitation - Impact Decision - Decennial Results - Savings per m^2				
Thermal Coefficient, U (W/m2.K) [31]	Asc. / Desc.	1,10		6,20		
	Asc. / Desc.	0,60		3,00		
Energy, Q (kWh/m^2.year)	Asc. / Desc.	17,67		113,10		
CO_2/year	185,49 g/kWh	3 277,83 g/m2		20 978,12 g/m2		24 441,44 g/m2
Radioactive Residues/year	9,92 µg/kWh	175,3 µg/kWh		1 121,91 µg/m2		1 307,13 µg/m2
Energy per 10 year (Eur/m^2)		30,04 €		192,26 €		222,30 €
Initial System Rehabilitation (Eur/m^2)		6,96 €		0,00 €		6,96 €
Initial System Maintenance per 10 years (Eur/m^2)		12,18 €		20,45 €		32,63 €
Disposable Initial System Value (Eur/m^2)		0,00 €		0,98 €		0,98 €
	Subtotal*WWR	41,06 €		41,17 €		82,23 €
Savings - Investment = Total						0,00 €
	Total - 10 years	-13,11 €		-69,22 €		-82,33 €
	Total - 20 years	25,93 €		-72,34 €		-46,41 €
	Total - 30 years	64,97 €		-75,45 €		-10,48 €

(*) EDP - Portuguese Major Electric Company Data, 2015 - http://www.edpsu.pt/pt/origemdaenergia/Pages/OrigensdaEnergia.aspx

[14] Excluding GHG emissions of used materials and solutions, its logistics and build operations.

1,500 m2 (L. Ambrósio, personal communication, March 29, 2018).[15] Both measures covering numerous buildings, but none received a complete renovation; some had external wall renovations and others window replacement [38].

4. Conclusions

This manuscript presents the outcome of a renovation, through a method that deduces investments by savings, assessing the solutions lifespan. Realizing the improvements and results, when is intended to apply the nZEB goals for existing social housing, in Lisbon.

Culture behaviors' have a significant role in the reduced amount of energy spent in acclimatization in Portugal, when compared to the EU, due to energy prices (considering the average wage), traditional comfort expectations, and a temperate climate.

The recent Portuguese crisis imposed financial constraints, with impact on the management of the social agenda and delays on investments and studies, with potential for attract National and EU's funds, to improve social housing. The research also emphasizes the lack of a detailed plan, in alternative to the goals in merely described in the Program advertising.

Plans on energy efficiency [11] should consider financial loans to tenants, limited to active systems, and under low interest rates, to update high consumption appliance and equipment (boilers, stoves, fridges, incandescent lights, et cetera). Additional renewal's sources on-site, as sun and wind power devices, even depending on weather, must be installed to promote the increase of savings.

The Portuguese Energy Agency (ADENE) has the mission to aware and inform the society to the importance of energy efficiency and water savings, and their relation with the environment, contributing to the 'energy literacy' [12]. For tenants of social housing, the research suggests the installation of new reading meters on power, natural gas, and water supply with the monetary value display, in alternative to existing solutions (Kw, m^3 and m^3).

Although the data surveyed and results presented are derived from the official Program promotion, procurement processes, and supplier interviews, the researchers emphasize the lack of an official report, which compiles the final results of the first Eco-Neighborhood Program operation, in Portugal.

In the future, it is intended to apply RoR-DG to other European Eco-Neighborhood experiences to discuss the best strategies.

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Technology, structure formation and properties of foam concrete on activated water of mixing

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Abstract

The results of studies of the foam concrete on activated water of mixing with the use of two types of foaming agent are demonstrated. It has been shown that activation of the mixing water increases the multiplicity and foam stability. The use of activated with the electromagnetic field and electric current water of mixing enhances strength characteristics and reduce shrinkage deformation of composites. The increase of water resistance of foam concretes prepared on activated water of mixing compared with control compositions it was established. The comparative characteristic of foam concrete on the two types of foaming agent is given.

Keywords: Foam concrete, composite, activation water of mixing, foam stability, foam multiplicity, durability, water resistance, shrinkage ;

1. Main text

Among the large variety of modern building materials used in construction, significant amounts fall on foam and aerated concrete. These materials are widely used in the construction of buildings and structures, in heat-insulating products. In recent years, the production of foam concrete has outpaced the use of aerated concrete. Due to the toughening of the thermal engineering standards for heat-insulating materials, it is important to improve the physical, mechanical and operational properties of foam concrete. Many authors have established that the quality management of concretes and other composite materials is possible with different impacts on both non-hardened and hard materials and on its components. At the same time, acoustic, magnetic, electrical, mechanical, laser and other effects are used largely [1-5].

Water is a required component for cement composites and water determines their technological properties. In our previous studies, we investigated the effect of electrochemical and electromagnetic activation (using electric current and the electromagnetic field to get changes in the physical and chemical properties of water) and proved the improvement of the physical and mechanical properties of cement stone and heavy concrete due to the use of activated mixing water [6, 7] . In this paper, we present studies of the production technology and physical and mechanical properties of foam concrete with the use of electrochemically and electromagnetically activated mixing water. From the results given below it follows that such mixing water activation in foam concrete gives an even greater effect. It is known that the formation of foam concrete with the optimal structure is possible under the condition of a combination of numerous physico-technical and physicochemical factors: the viability of the foam film, composition, density and other properties of the foam concrete.

The hydrodynamic effect is one of the factors determining the viability of the foam film. According to the theory of structural and mechanical stability of foams, the stability of adsorption layers is determined both by surface forces

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and by mechanical properties of foamed films [8]. If there is some way to improve these properties, it will increase the stability of foam. It is the provision of a structural-mechanical stability factor that can give the foam the greatest stability. Below we present studies of the effect of activated water, both on the foam properties and on the properties of foam concrete.

The ability of surfactants to form micelles to a significant extent depends on the length of hydrocarbon radical [8]. Their sizes depends on the concentration above which micelles form (the critical micellization concentration, CMC) [9]. There are many methods for determining CMC. All of them are based on a sharp change in the physicochemical properties of surfactant solutions in the transition from a molecular solution to a micellar solution.

Thus, the creation of a foam and mixtures of foam concrete with stable structure possible with the use of activated water and aqueous solutions for mixing.

2. Description of the conceptual design

To study aqueous solutions of foaming agents, foam, cement stone and foam concrete, we used the following components: we took portland cement CEM I 42.5 B as a binder (GOST 31108-2003); as foaming agents: “Esapon 1850” - non-ionic surfactant, which is a saturated fatty alcohol with ethylene oxide, and "Arekom-4" (TU 2481-007-11084661-2003) - foaming agent, which is an aqueous solution of anionic surfactants and auxiliary additives; as a solvent, we used water that meets the requirements of GOST 23732-79.

We carried out the activation of water and aqueous solutions using the unit for the anti-scale treatment of water systems UPOVS2-5.0 by "Maxmir" [10]. We conducted experimental research in accordance with the operation modes of the apparatus. In total, we used nine modes, the cipher of which is composed of alphanumeric characters. The letter designation E + M means that the natural water or its solution has been subjected to joint successive activation by an electric current (electrochemical activation) and an electromagnetic field in the working gaps of the apparatus. The digital designation corresponds to the selected mode of operation of the device, which characterizes the current strength (switch position) in the cell circuit and the winding of the magnetizing coils. The modes and their parameters are presented in table 1.

Table 1. Activation modes of water and aqueous solutions

Water activation mode	Current density j_{max}, A/m^2	Electromagnetic field strength H_{max}, kA/m
E+M (1-1)	5,65	24
E+M (1-3)	5,65	75
E+M (1-6)	5,65	135
E+M (3-1)	22,58	24
E+M (3-3)	22,58	75
E+M (3-6)	22,58	135
E+M (6-1)	43,55	24
E+M (6-3)	43,55	75
E+M (6-6)	43,55	135

We used a stalagmometric method to study the indicator of the critical micelle concentration of Arekom-4. The surface tension values of the solutions are shown in Table 2. The critical concentration of Arekom-4 foaming agent was calculated for each type of water according to the curves of the surface tension versus the concentration of the foaming agent. The values of the CMC are given in Table 2.

Based on the tabulated values of the surface tension of the solutions, we constructed the graphical dependencies shown in Fig. 1.

We can see that the curves of the dependence of the surface tension on the concentration of the foaming agent for some types of activated water (1-3, 3-3 and 6-3) differ slightly from the other curves. However, there is no sharp difference between them.

Table 2. Dependence of the surface tension of activated water on the concentration of Arekom-4 foaming agent

Water type	Surface tension, mJ / m²						CMC, %
0	72,75	34,68	29,50	29,05	27,79	27,88	0,26
E+M (1-1)	72,75	34,96	29,00	28,32	27,53	27,28	0,25
E+M (1-3)	72,75	33,02	28,33	27,96	27,45	26,63	0,25
E+M (1-6)	72,75	35,79	30,00	28,87	27,19	26,09	0,24
E+M (3-1)	72,75	34,28	30,03	29,19	27,45	26,36	0,24
E+M (3-3)	72,75	36,23	30,96	29,89	27,79	26,79	0,24
E+M (3-6)	72,75	34,62	30,39	29,76	28,32	26,95	0,26
E+M (6-1)	72,75	34,55	30,10	29,05	28,23	26,79	0,24
E+M (6-3)	72,75	36,53	29,13	27,28	26,95	26,87	0,27
E+M (6-6)	72,75	35,37	30,54	29,53	27,28	26,79	0,25
W, %	0,0	0,2	0,4	0,6	1,0	2,0	

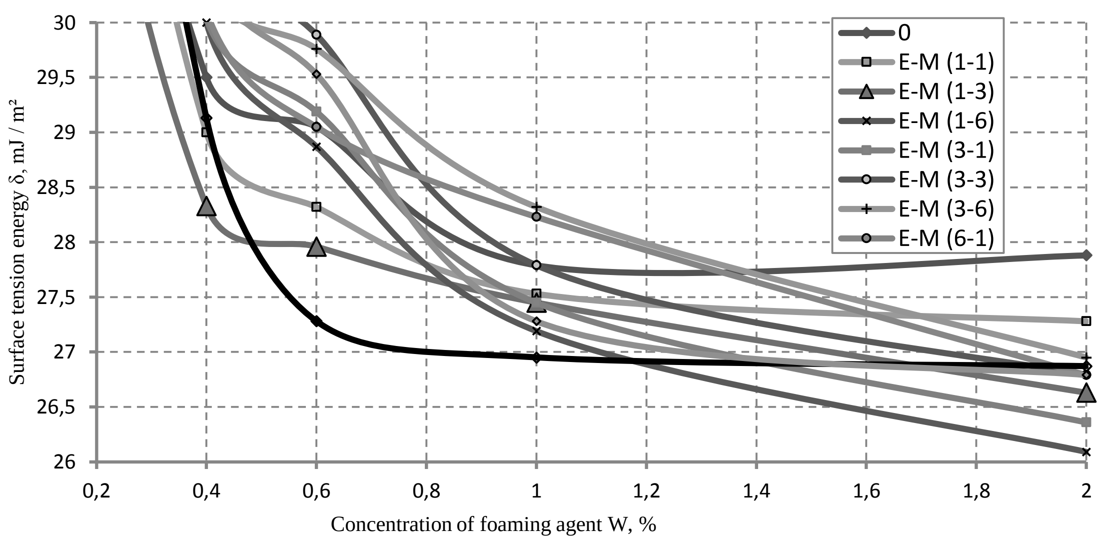

Fig. 1. Dependence of surface tension on the concentration of foaming agent

From the results of studies it follows that the critical concentration of foaming agent Arekom-4 is in the range 0.2 ... 0.3%.

Various properties of the foam influence on the structure formation and hardening of the foam mass, they affect the subsequent performance of buildings constructed from foam concrete.

To assess the quality of foaming of the solutions and the prepared foams we have investigated the multiplicity and stability of foam.

We determined the foam multiplicity of Arekom-4 and Esapon 1812 foaming agents in accordance with TU 2481-007-11084661-2003.

As a solvent for foaming agents, we used non-activated water and water activated according to the regimens given in Table 1.

Test results for the determination of the foam multiplicity for Arekom-4 and Esapon 1812 foaming agents with the use of activated water are shown in Fig. 2.

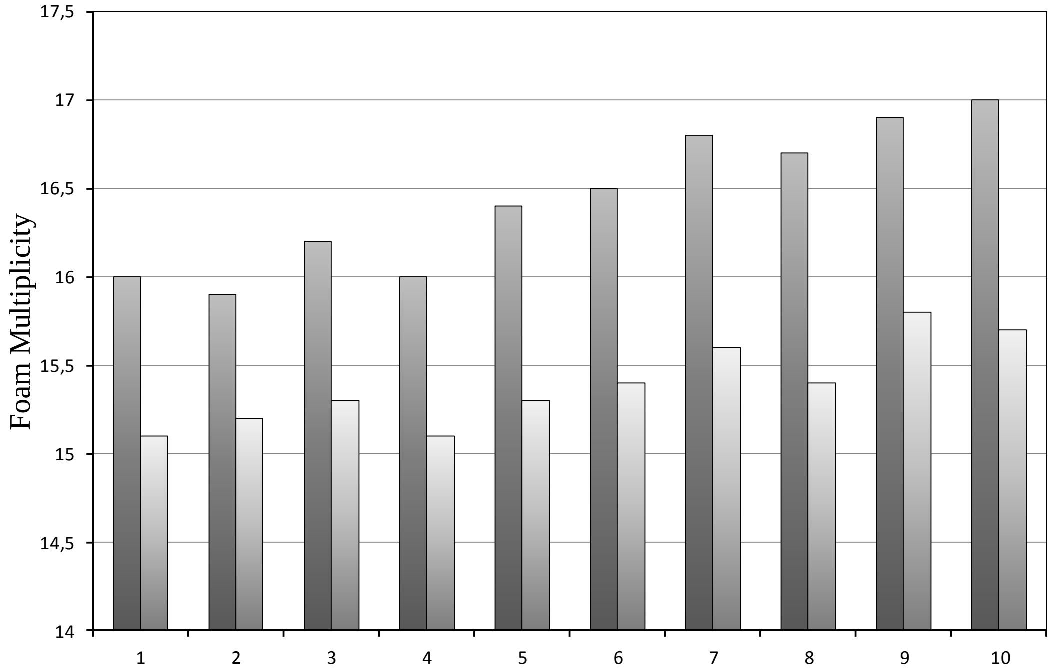

Fig. 2. Change of the foam multiplicity for Arekom-4( ) и Esapon 1812( ) on the mode of water activation:
1) non-activated water; 2) water activated according to the '1-1'; 3) water activated according to the '1-3'; 4) water activated according to the '1-6'; 5) water activated according to the '3-1'; 6) water activated according to the '3-3'; 7) water activated according to the '3-6'; 8) water activated according to the '6-1'; 9) water activated according to the '6-3'; 10) water activated according to the '6-6'

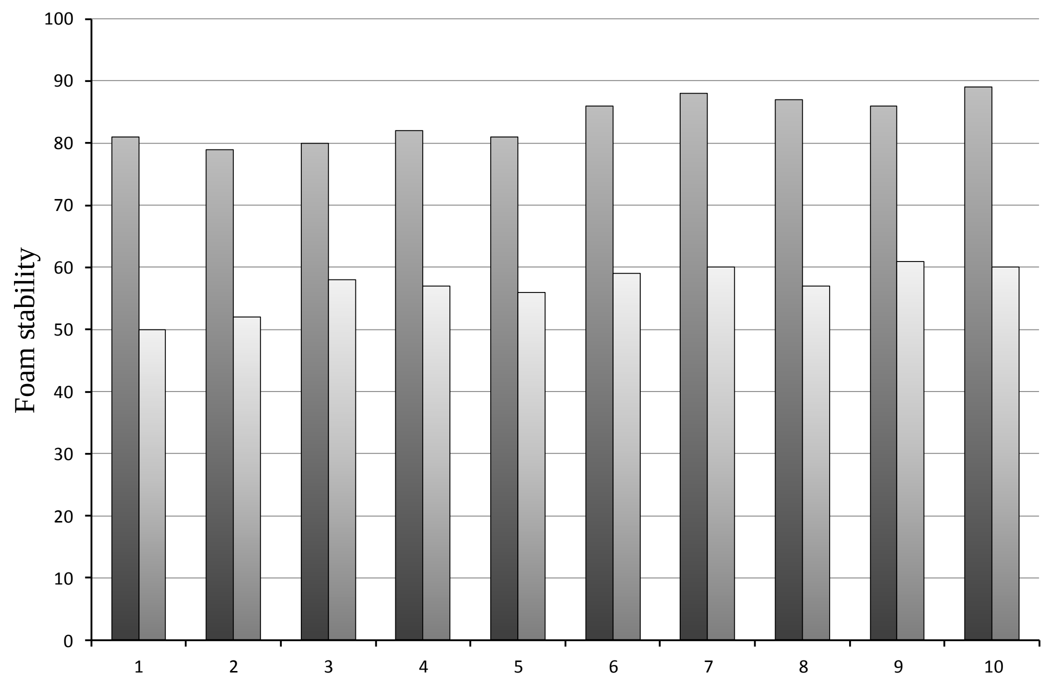

Fig. 3. Change of the foam stability for Arekom-4 ( ) и Esapon 1812 ( ) on the mode of water activation:
1) non-activated water; 2) water activated according to the '1-1'; 3) water activated according to the '1-3'; 4) water activated according to the '1-6'; 5) water activated according to the '3-1'; 6) water activated according to the '3-3'; 7) water activated according to the '3-6'; 8) water activated according to the '6-1'; 9) water activated according to the '6-3'; 10) water activated according to the '6-6'

It follows from the figure that with increasing current in the conductor of magnetizing coils and in the working gap of the electrodes, the multiplicity of the foam increases.

We determined the stability of the foam in accordance with TU 2481-007-11084661-2003.

The results of tests for determining foam stability of foaming agent Arekom-4 and Esapon 1812 using activated water are shown in Fig. 3.

It follows from the figure that with increasing current in the conductor of magnetizing coils and in the working gap of the electrodes, the stability of the foam increases with the use of both types of foaming agents.

Obtaining an effective insulating material with low density (less than 500 kg / m^3) and low thermal conductivity remains one of the main tasks in the production of foam concrete. For its implementation, it is necessary to pay special attention to the technology of manufacturing this material, in particular, to the choice of the foaming agent type, the selection of the water-hard ratio, and the quality of the cement. Modification of the mixing water will have a definite effect on the material properties of cellular structure.

We examined the foam concrete on 2 types of foaming agent: Arekom-4 and Esapon 1812. We present the results of the dependence of the foam concrete strength on the water activation mode in Fig. 4.

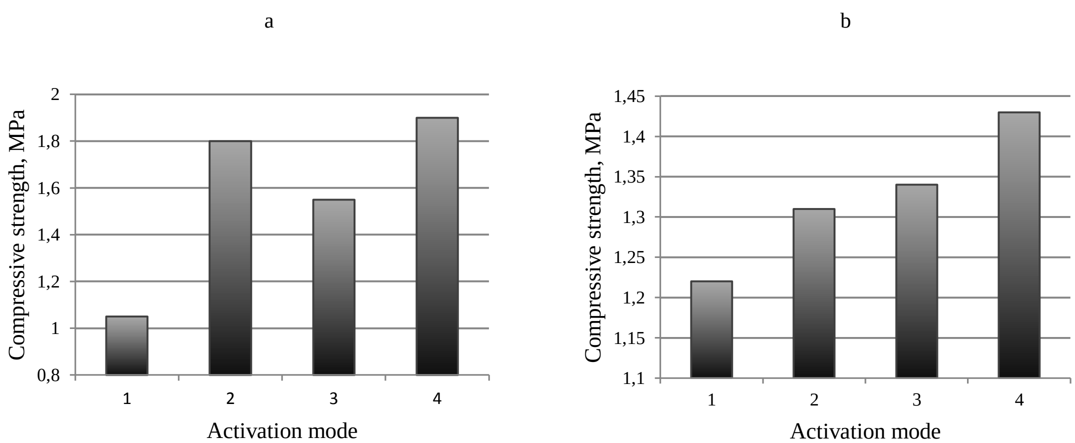

Fig. 4. Dependence of the change in compressive strength of foam concrete with the foaming agent Arekom-4 (a) and Esapon 1812 (b) on the type of activated mixing water: 1 - water not activated; 2 - the same, processed by a magnetic field; 3 - the same, treated by electric current; 4 - the same, treated by the combined action of an electric current and a magnetic field

We can see from the figure that the use of activated mixing water promotes an increase in the strength characteristics of composites. The water treated by the combined action of electric current and magnetic field makes it possible to increase the compressive strength of foam concrete on the Arekom-4 up to 90%, and on the Esapon 1812 – up to 18%.

Shrinkage is an important property of foam concrete. Shrinkage of foam concrete during drying should not exceed 3 mm / m (for non-autoclave technology materials according to the requirements of GOST 25485-89). Otherwise, the shrinkage strain will cause cracking. This is especially observed in the case of manufacturing large-size products, which include wall structure and slab coverings. According to practical experience of foam concrete application, the width of crack opening in similar products can reach 3...5 mm.

When performing research, the shrinkage was determined on samples in the form of prisms of size 4×4×16 cm. Deformations were measured by dial indicators. Study results of the foam concrete shrinkage (samples were composed with the use of two types of foaming agents and activated mixing water) are shown in Fig. 5.

From the data given, we can see that the greatest growth of shrinkage deformations occurs in the first 5-7 days, and then stabilization of shrinkage is observed. It also follows from the results of investigations that the treatment of activated mixing water by electromagnetic field and electric current helps to reduce shrinkage deformations. Here, apparently, a significant role is played by the dispersed phase formed as a result of the mixing water activation. From the considered activation variants, the E + M mode (6-6) is the best of them. In this case, shrinkage reduction is more than 10%. The tests also showed that less shrinkage occurs in the materials on the Arekom-4 foaming agent.

It is well known that foam concrete quickly absorbs water into its pores during operation in conditions of high humidity or while standing in water. The change in the moisture content of concrete affects not only its insulating

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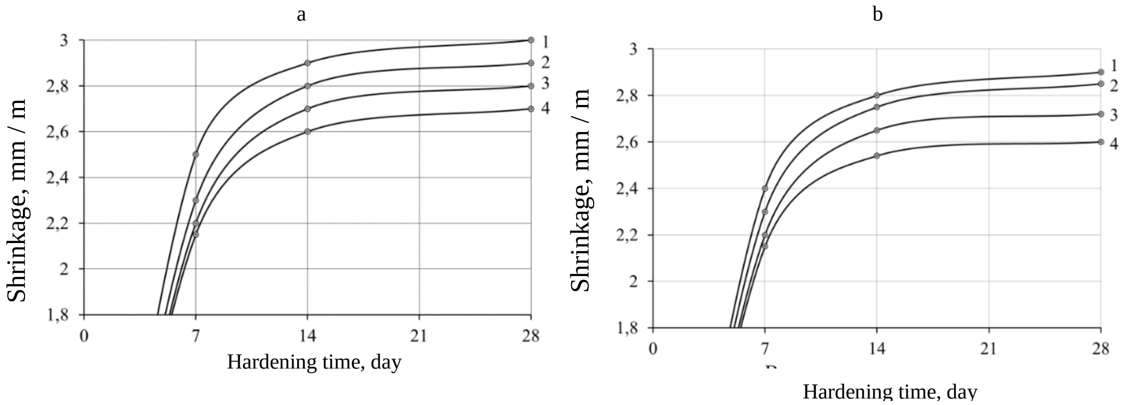
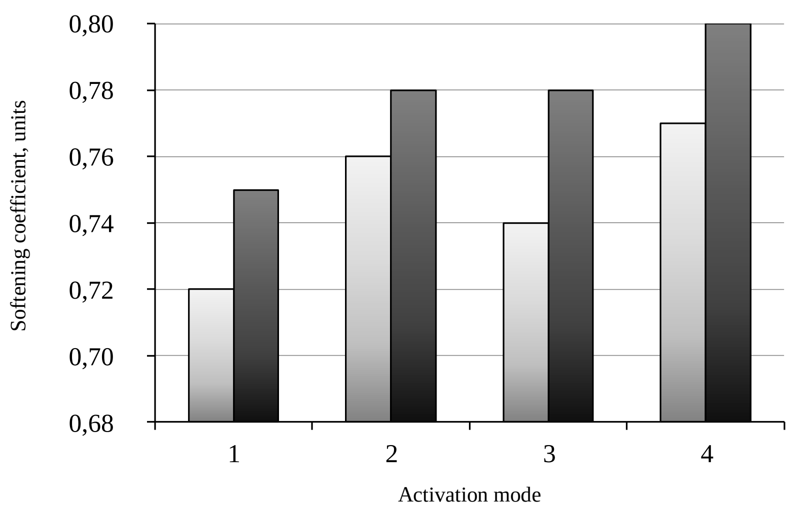


Fig. 5. Dependence of foam concrete shrinkage with foaming agents "Esapon 1812" (a) and "Arekom-4" (b) on the activation mode of mixing water: 1) water not activated; 2) water activated by the E + M mode (1-1); 3) the same, E + M (3-3); 4) the same, E + M (6-6)

properties. This phenomenon is also associated with the development of moisture shrinkage. In the presence of moisture, the material swells, and when dried, it shrinks. Emerging stresses (due to changes in humidity) loosen the structure of the material and reduce its strength. Humidity deformations, in the first place, depend on the ratio of gel-like and crystalline phases in the cement stone. The resistance of the material increases in such conditions with increasing crystalline phase. In this case, it is important to increase the strength of the structural mesh from the hardened cement stone in the porous system. Previous studies (6, 7) showed that mixing cement with activated water, contributes to a significant increase in strength of cement stone. It was found that with the same degree of hydration and porosity, the strength of the cement stone depends on the nature of the hydrates crystallization. The high strength of cement stone was noted in the compositions with the optimal combination of weakly crystallized hydrates with dense sections of the crystallized structure. Weakly crystallized hydrosilicates are apparently a binder cementing unreacted clinker grains, as well as crystals of calcium hydroxide and ettringite hydroxide. The density of the material significantly affects the water resistance of the cement compositions, in addition to the above factors. One of the main factors affecting the density, regardless of the initial water-cement ratio, is the form of water-solid interface. Water, as known, is one of the main elements that form the structure of cement stone; water is involved in the formation of hydrate compounds and the formation of pores.

Studies of the water resistance of foam concrete were carried out on samples measuring 4 × 4 × 16 cm. The test results of samples after 3 days of incubation in the environment shown in Fig. 6.



Arekom-4 (■) и Esapon 1812 (□)

Fig.6. Dependence of the softening coefficient of foam concrete on the mixing water activation mode: 1) water, not activated; 2) water activated by the E + M mode (1-1); 3) the same, E + M (3-3); 4) the same, E + M (6-6)

Studies show an increase in the water resistance of foam concrete prepared on activated mixing water, compared with the control compositions on average by 10%.

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The analysis of the influence of the corrosion protection method of selected steel elements on the steel structure life cycle costs

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Abstract

Steel products are widely used in the construction for the performance of essential and additional elements of engineering structures. They are characterized by high tensile strength, compression and bending, the structure homogeneity, the possibility of assembly regardless of the season and climatic conditions, ease of processing and the possibility of almost any shape. The main disadvantage of steel structures is their high susceptibility to corrosion, which depends on local operating conditions and the type of applied corrosion protection system.
The aim of the research carried out by the authors is to indicate the possibility of reducing the costs associated with anti-corrosion protection, incurred at the stage of operation of the steel structure over a period of several decades. The scope of the research includes the life cycle cost analysis for selected steel elements using three alternative corrosion protection systems.
The subject of the research is the analysis of the influence of the corrosion protection method of selected steel constructions on its life cycle costs.
On the chosen example of the selected object and problems related to its use and maintenance, the possibility of using a single-layer protection in the form of a metallization coating made in a hot-dip galvanizing process, a three-layer varnish coating based on liquid paints and protection composed of a galvanized metallization coating and a two-layer paint coating is considered. The assessment is carried out in accordance with the life-cycle cost estimation algorithm (LCC).

Keywords: steel construction; steel protection; life cycle cost; anti-corrosion protection; corrosion;

1. Introduction - anti-corrosion protection systems

Analyzing the advantages and disadvantages of the corrosion-resistant coatings that can be applied in practice, protecting steel components of engineering structures, their durability, full protection against corrosion and economic considerations should be taken into account. It is important to compare the costs incurred at the stage of assembling the elements and making the protective coating with the costs generated during their maintenance and use. The total life cycle cost of a given corrosion protection system includes the cost of its implementation as well as the costs of renewals, regenerations, repairs (within a defined range) and re-implementation (to the full extent). Table 1 presents an example comparison of protection in the form of hot dip galvanizing with two painting systems. The paint systems adopted for the analysis differ in terms of the preparation of the steel surface and application of the coating material, which corresponds to two conditions for the preparatory work and the estimated durability of the systems over time.

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Table 1. The comparison of the essential features of anticorrosion protection in the form of a galvanized layer and paint coatings

Operation	Hot dip galvanizing	Painting system 1	Painting system 2
surface preparation	chemical treatment included in the price	abrasive blasting mechanical treatment	manual
priming coat	-	1	1
topcoat	zinc, 85 µm	2	2
durability	50 years	11 years	8 years
repair	-	over periods of 11 years	Over periods of 8 years
implementation and repairs costs in [%]	100	169	198

source: [1]

Analyzing the total life cycle costs of a given type of corrosion protection, generated in the long-term perspective (e.g. 50 years) should be considered in the aspect of durability of structure corrosion protection (Figure 1).

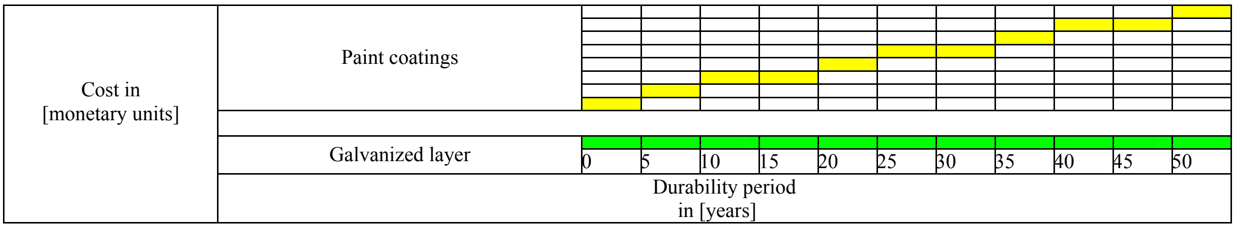

Fig. 1 Costs for maintaining the durability of anti-corrosion protection in the form of paint coatings and a galvanized layer
source: own study based on [1]

The fast aging time, loss of elasticity, cracking and scratching of paint coatings, which constitute anti-corrosion protection of the steel structure, consequently contribute to a significant reduction of its durability (Figure 2).

a) b)

Fig. 2. The protection ofobject elements applied on one object
a) galvanized steel barrier, b) protective pillar

The need to repeat every few years the labor-intensive and costly maintenance and repair procedures causes that the costs of this type of protection increase over time (Figure 1). The cost of protecting the steel structure in the form of a galvanized layer remains for a longer period, and in principle the whole period of use at a constant level, which is caused by the lack of treatments related to its renewal and repair. From the user's point of view, it is also important to maintain the steel structure in a proper technical and aesthetic condition. Renovation of paint coatings of steel supporting or auxiliary structures in the operated facility is often associated with numerous technological and organizational difficulties. A serious problem is the proper preparation of the construction surface for painting and the application of a new coating on the element entire surface. Therefore, it is important to design and manufacture anti-corrosion coatings in order to make them stable for long life, when only temporary repairs of local damage are made [2].
Attention should also be paid to the level and quality of information contained in design and technological studies for

the structures being made. They should also apply to adequate corrosion protection.
An important issue related to the selection of a given type of corrosion protection of a steel structure is also its impact on the natural environment, health and safety conditions and hazards during the application of protective coatings [3].
At the design stage, the type of applied anticorrosion protection system should be analyzed in the context of its suitability, the possibility of maintenance [4, 5] and the impact on the environment. The use of liquid anticorrosive materials for the production of protective and decorative coatings is associated with the emission of significant amounts of volatile organic compounds VOC into the environment, whose source are all auxiliary preparations applied in preparatory works in the form of solvents, removers and as liquid paints used to make coatings. Depending on the type of film-forming material, the amount of organic volatile compounds contained in paint products ranges from 250 - 850 grams/liter of products in a ready-to-use state. During the process of binding coatings, these compounds evaporate into the environment, which contributes to both local and cross-border formation of photochemical oxidants in the tropospheric boundary layer by ozone formation, as well as to the development of asthmatic diseases in people exposed to them [6, 7, 8].

2. The life cycle cost

The life cycle cost estimation (LCC) is an economic analysis process aimed at assessing the total cost of acquisition, possession and liquidation of a product (construction, facility) [9, 10]. In broad terms, the analysis provides important data relevant to the design, development, use and disposal of the product (construction, facility). The estimating of life cycle costs can also be effectively applied to the assessment of costs associated with specific activities, e.g. to assess the results of various methods of operating products, structures, objects [11].

The lifecycle cost of steel elements protected against corrosion by a specific technology, their lifetime and reliability depend on many factors. These include the scope and detail of the technical design, the quality of construction and assembly of the structure, the scope and the possibility of carrying out work related to its maintenance and operation. The authors look for connections between decisions made at the planning and design stage and costs incurred at the stage of maintenance and use of steel constructions.

3. The analysis of cost of the steel construction in the aspect of three selected anti-corrosion protection systems

The article takes into consideration protection of steel elements using three alternative coating systems for corrosion protection:

- the metallization coating with a thickness of approximately 85 μm made in the process of hot dip galvanizing method - system I,
- the three-layer paint coating made on the basis of liquid paints with a total thickness adapted to the corrosive conditions of the operating environment - system II,
- the double protection consisting of a zinc metallization coating with a thickness of approximately 85 μm and a double-layer paint coating with a thickness of approximately 150 μm, which acts as an additional corrosion protection system for the galvanized coating and provides appropriate color values of the structure - system III.

According to the assumption adopted at the design stage, all proposed corrosion protection systems should meet the protective requirements for more than 15 years, and protected steel elements should ensure safe operating conditions for at least 40-50 years, i.e. the planned lifetime of the object.

In order to determine the initial and maintenance costs for each of the three proposed anti-corrosion systems, the authors made an analysis, which results are presented in the following chapter. The following assumptions were adopted: the steel structure service lifetime assumed for analysis - 30 years, the discount rate - 1.75%, for system II and III every 5 years, on the 5% of the construction area are performed works related to cleaning, repair and renewal of anti-corrosion coatings (cleaning jet, washing, degreasing, painting), every 15 years on 20% of the steel construction area are performed works related to stream cleaning, washing, degreasing and painting, every 15 years on 100% of the surface are performed works related to painting the topcoat. The current market prices of materials and information obtained from steel structures users were applied.

From the user's point of view, it is important to determine the initial costs, including the cost of the steel structure, its assembly and protection in the form of a protective coating (Figure 3).

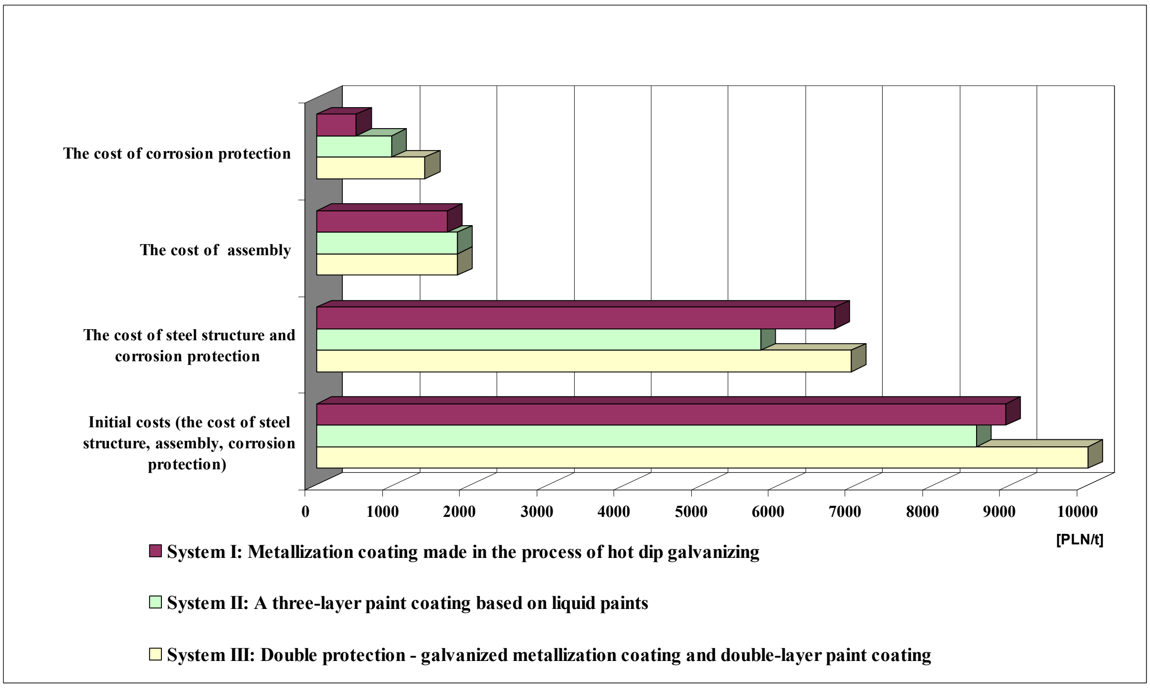

Fig. 3 Initial costs (the cost of steel structure, assembly, corrosion protection) for three corrosion protection systems for steel structure: source: own study

It is also important to compare the initial costs with the costs generated during the steel structure lifetime (Figure 4). These expenses result from running, at specified intervals, renewal, recovery, repair and protection works, but also the re-implementation of the protection in the full scope (Figure 5).

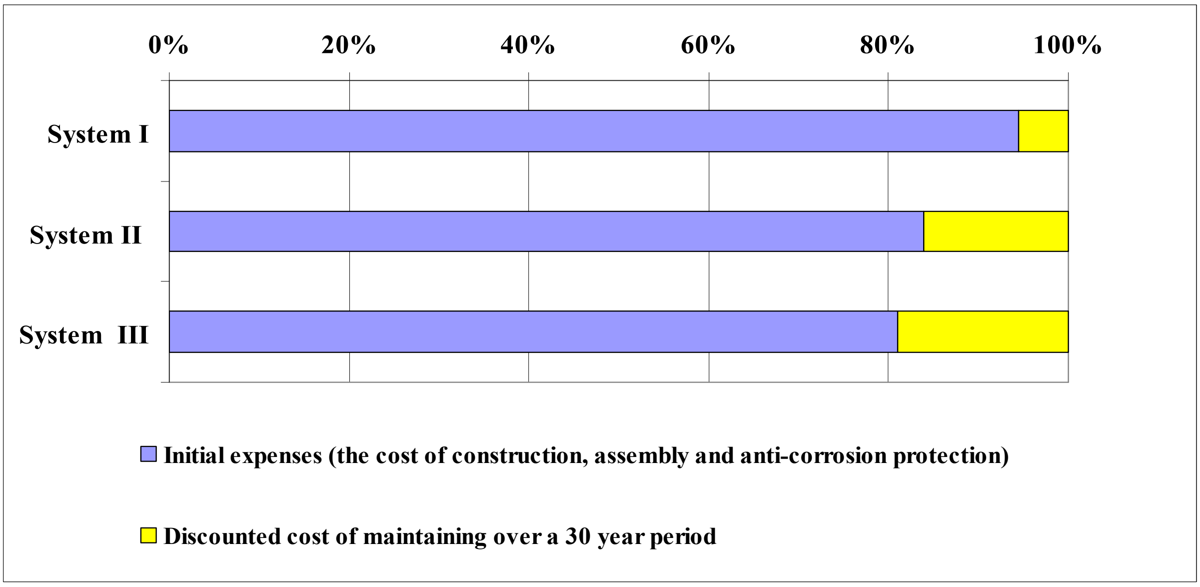

Fig. 4. Total costs (initial expenses and discounted maintenance costs of the structure) incurred over a 30 year period

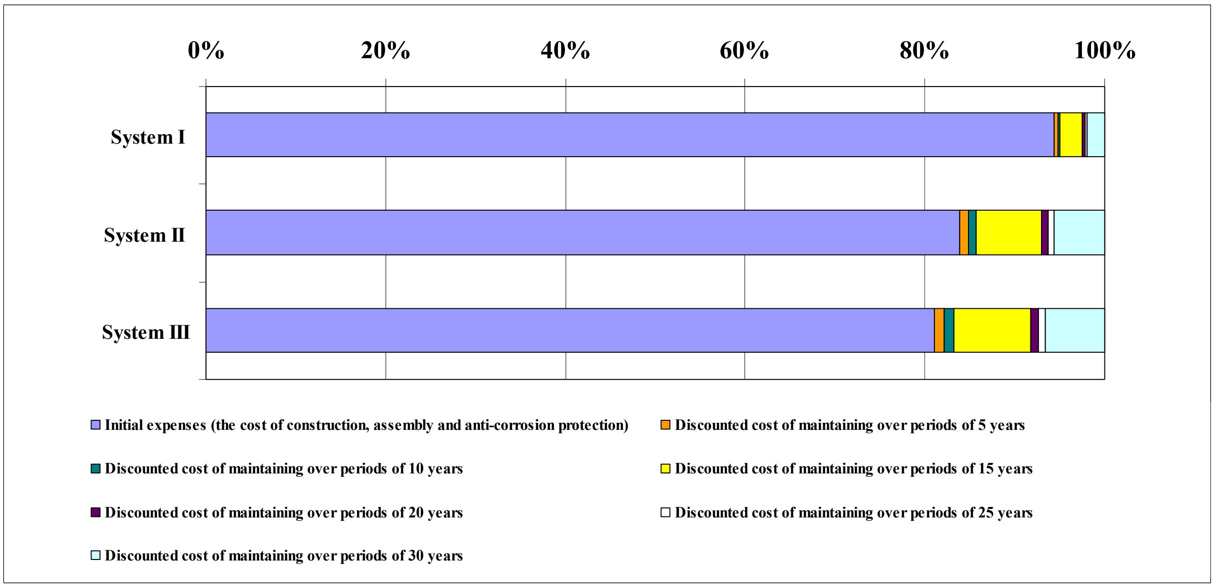

Fig. 5 Detailed total costs (initial expenses, discounted costs of structure maintenance and cleaning) incurred over a 30 year period

In the light of the above analyzes, it can be concluded that taking into account only the initial cost (Figure 3), the most expensive anti-corrosion protection is system II, followed by the I and III. Taking into account the discounted costs of maintaining the steel structure in 30 years, protected against corrosion according to the proposed technology - the most expensive solution is system III, followed by II and I. It can be concluded that in the long term, anti-corrosion protection in the form of paint coatings (system III and II) are more expensive solutions. The fast aging process of painting protective coatings, loss of elasticity, scratches, cracks and flaking result in a significant reduction of their durability with the passage of time.

In practice, this means that every 5 - 8 years must be repeated labor-intensive and costly process of maintenance and repair in the form of applying new paint coatings. The use of steel structure protection system in the form of a galvanized layer, in the course of operation, does not require the need to undertake costly maintenance activities. When assessing the total life-cycle cost, i.e. the initial effort and the 30-year maintenance period of the steel structure protected in the three analyzed systems, it can be concluded that the cheapest solution is system I - steel structure protected with a metallization coating made in the hot dip galvanizing process, and anti-corrosion protection in the form of anti-corrosive painting coatings made on non-galvanized and galvanized steel elements are more expensive solutions - in the long run, they generate significant expenses incurred by the user.

4. Conclusion

The solution, based on the applied LCC analysis, allows to reduce the costs of maintaining the steel structure in the scope of anti-corrosion protection, while maintaining certain construction safety standards. The considerations presented in the article confirm the long-term financial benefits for the user, resulting from the use of anti-corrosion protection in the form of a galvanized coating made in hot dip galvanizing technology, also justifying the use in practice - including in the steel structure design process, the LCC analysis. Its use allows to indicate the optimal solution in terms of the total lifecycle cost, taking into account initial outlays as well as costs incurred in the course of operation on the construction.

Limiting the use of volatile organic compounds applied to produce both the first protection and its subsequent repairs effectively reduces the need for paint products and the production of all types of solvents containing volatile organic compounds.

The use of galvanized coatings also significantly reduces the waste generated during the blasting of the steel material surface itself to be prepared for protection as well as subsequent wastes arising from the removal of rust and damaged paintwork from elements subjected to subsequent repair and renovation.

It can be therefore concluded that the method of anti-corrosive protection of steel components of engineering structures has a direct impact on the cost of their life cycle considered in the long-term perspective.

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The rigid and flexible road pavements in terms of life cycle costs

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Abstract

The cost of road pavement construction, its durability and reliability depends on many factors, including: the scope and detail of the technical design, quality of work but also the scope of works related to its maintenance, conservation and operation. Determining the amount of rational expenses, in terms of the life cycle cost of the pavement, requires determination and consideration of the above issues, already at the planning and design stage. In many cases, the ordering party analyzes only the initial investment costs, omitting the operating expenses for the pavement in the long term. The article points out the link between decisions taken at the planning and design stages and expenses incurred at the stage of maintenance and use of road pavement. The authors analyse and compare life cycle costs for two technologies of making road pavement - flexible (asphalt pavement) and rigid (portland cement concrete - PCC) and three categories of road traffic. Referring to the methodology included in [1], the authors present an example of the LCC analysis and determine the individual cost components: construction, renovation and maintenance during the period of 30 years. The analysed costs were determined based on the expert knowledge and current price publications.
The authors draw attention to the fact that low costs incurred by the ordering party at the stage of investment implementation, in the course of use and maintenance of the pavement, entail significant expenses in the long-term. The authors also indicate difficulties related to the estimation of the cost of the road pavements life cycle.
The main reasons include the lack of designers' knowledge about the technology of pavement repairs and related costs, as well as the lack of a simple model for calculating life cycle costs, which is a tool for supporting investment decisions and indicating the optimal solution already at the design stage.

Keywords: road pavement construction; life cycle costs; LCC analysis; flexible pavement (asphalt); rigid pavement (concrete);

1. Introduction

The basis for making any investment decision, including the construction of road infrastructure, is the Life Cycle Cost Analysis. Its scope covers the purchase, ownership and liquidation costs of the structure. In the light of the obligation to rationally spend public funds, entities responsible for road infrastructure are obliged to demonstrate that the activities carried out are highly effective. Therefore, they are looking for tools of economic analysis that will help in choosing the right solution. The LCC method makes possible to estimate the costs of alternative solutions for new projects, but also those already in operation, indicating variants generating the lowest costs over the life span.

The policy of sustainable development of the economy currently implemented in the EU is directed for activities related to environmental protection. According to this idea, at the stage of designing new road constructions, the cost of their construction, rebuilding and maintenance for a long time should be taken into account. All solutions that have no negative impact on the environment, including recycling, energy saving and efficient use of raw materials are widely promoted. Road projects are supported, which are characterized by low costs in the course of their operation. It is estimated that taking into consideration the life cycle in the road pavement design may contribute to a reduction of up to 5% of annual expenses for their maintenance.

The aim of the article is to analyse and compare lifecycle costs for two technologies of making road pavements -

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flexible (asphalt pavement) and rigid (PCC pavement), including construction, renovation and maintenance costs over a period of 30 years. On this basis, the authors indicate the optimal solution from the road pavement life cycle costs point of view and the assumed traffic category.

2. The application of LCC in the road construction

The costs of maintaining and using road pavement constitute a large part of the annual expenses of companies responsible for the above activities. The frequency and scope of maintenance and repair works in a given period related to the maintenance and use of a given type of road surface depends on its lifetime. They are affected by accepted design standards, the quality of the constructed structure and the strategy and quality level of the carried out maintenance activities. Determining the road surface optimal life cycle cost requires estimating the size of the above components.

A characteristic feature of the road infrastructure implementation is a high initial investment, but also assumed long service life, which can be extended through systematic repairs and proper maintenance. The task of road infrastructure is to meet the need for safe and economical people and goods transport, while ensuring certain quality standards (e.g. the resistance to slippage) and requirements (e.g. smooth ride, low impact on the environment). The task of the owners and managers of the road infrastructure is to ensure proper traffic conditions for the period of its operation. However, the traditional approach to design often does not take into account the requirements and costs of maintaining road pavement.

As a result of the growing demand for transport, the number of vehicles and the volume of traffic on the roads increases. This results in increased degradation of road infrastructure elements, air pollution and noise emission (deterioration of health and quality of life of local residents) and increased sensitivity of road systems to traffic disruptions caused by maintenance works (renovation, repairs, replacements), collisions and road accidents [2]. The functionality of the road infrastructure is expressed above all in ensuring the continuity of its operation in the assumed period. Continuity of operation is based on the constant provision of appropriate quality parameters for road users to transfer and receive information, drive a vehicle, safety etc. Managing the functionality of road infrastructure means maintaining its high level of readiness to operate by monitoring basic parameters (e.g. the degree of degradation of the surface, loss of its technical parameters), also changing as a result of maintenance and renovation. The scope and frequency of conducting works related to the maintenance and use of road pavement are essential elements affecting their functionality and operating costs [3].

The costs of maintaining and using road infrastructure are of interest many research centres around the world [2,4,8]. The life cycle cost analysis is the process of evaluating the overall economic value of a project by analysing initial costs and discounted financial outlays incurred over a longer period. The comprehensive LCC analysis includes initial costs (road construction), costs related to maintenance and use (renovation, repair, replacement, maintenance, reconstruction and restoration) but also costs incurred by road users, such as delays due to repair and maintenance work (loss of time) or accidents and traffic collisions.

Factors which, according to the authors, have an impact on the costs associated with the maintenance of road pavement activities, are [4]:

- season of the year (winter, summer),
- road conditions,
- accepted standard of maintenance,
- the course of the road: straight section, road curve,
- the type of road,
- the intensity of vehicles (average annual daily intensity of vehicles),
- the type of passing vehicles,
- the load-bearing capacity and durability of the surface,
- permissible speed on the road section,
- the number of lanes on the road,
- regional conditions.

For the analysis of two variants (flexible and rigid pavement) to estimate the component costs (acquisition, ownership) the following methods were applied:

- the engineering method of cost estimation (direct product testing, component after component),
- the method of cost estimation by analogy (the estimation based on the experience of experts with similar products and technologies),

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- the parametric cost estimation method (available parameters and variables were applied to develop the cost estimation dependency).

3. Assumptions adopted for the analysis

In order to make an analysis, the authors adopted the assumptions described below.
1. Two basic types of pavement constructions were analysed:
- type 1 – the flexible pavement with asphalt layers and the base course layer made from unbound mixture materials,
- type 2 – the rigid pavement with portlant cement concrete (PCC) slabs and the base course layer made from materials treated with hydraulic binders.

2. Individual types of pavement constructions were proposed in accordance with the current Polish catalogues of typical pavement constructions that have been applicabled since 2014 [5, 6, 7].

Table 1. The diagram of the pavement structure layers of flexible pavement and improved subgrade layer, after [5]

Pavement structure	Upper layers of the pavement structure	Wearing course layer	
		Binder course layer	
		Base course	The upper layer of the base course
			The bottom layer of the base course
	Bottom layers of the pavement structure	Subbase layer	
		Frost protection layer	
Subgrade	Layer of improved subgrade		
	Native soil in cutor embankment (fill), qualified to one of the subgrade classification from G1 to G4		

source: own study based on [5].

Table 2. The diagram of pavement structure layers of rigid pavement and improved subgrade, after [6]

Pavement structure	Upper layers of the pavement structure	PCC concrete slab
		Sliding layer
		Base course layer
	Bottom layers of the pavement structure	Subbase layer
		Frost protection layer
Subgrade	Layer of improved subgrade	
	Native soil in cutor embankment (fill), qualified to one of the subgrade classification from G1 to G4	

source: own study based on [6].

Table 3 The list of layers thicknesses of flexible and rigid pavements for KR6 traffic category, after {5, 6]

The flexible pavement with asphalt wearing course and base course with the unbound aggregate (cm)		**The rigid pavement** with Portland Cement Concrete slab in the wearing course and base course with mixture treated by hydraulic binder (cm)	
Heavy traffic - traffic category KR6			
22.0 – 52.0 mln axles of 100 kN during the design period of 30 years		**42.63 – 101.25 mln axles of 100 kN during the design period of 30 years**	
4 cm	The wearing course layer of asphalt mixture	27 cm	The wearing course layer – PCC with dowels
8 cm	The binder course layer of asphalt mixture	-	The slippery layer: geotextile
16 cm	The base course layer of asphalt concrete	18 cm	The base course layer of aggregate mixture bound with a hydraulic binder C 8/10
20 cm	The sub-base layer of unbound aggregate mixture	15 cm	The basic sub-base layer of a mixture bound with a hydraulic binder C5/6
15 cm	The sub-base layer of aggregate mixture bound with hydraulic binder	20 cm	Capping layer of unbound aggregate mixture
20 cm	Capping layer of unbound aggregate mixture	25 cm	Improved subgrade stabilized with hydraulic binder or lime
25 cm	Improved subgrade stabilized with hydraulic binder or lime		
83 cm	Subgrade	81 cm	Subgrade

3. For each type of pavement structure (type 1 – asphalt pavement, type 2 – PCC pavement), typical constructions for heavy traffic (traffic category KR6), medium (traffic category KR4) and light traffic (category of traffic KR2) were adopted.

4. The arrangement of the flexible pavement structure layers is presented as in Table 1. The variant in cut (with high groundwater level and poor soil conditions) is analysed. A rigid pavement construction system was adopted and presented in Table 2.

5. For the purpose of stablishing the LCC, the authors analyzed three selected representative traffic categories - according to [5, 6, 7], representing heavy traffic (KR6 traffic category), medium traffic (KR4 traffic category) and light traffic (KR2 traffic category).

6. The construction of the flexible pavement (asphalt layers) - the upper layers of the pavement structure for the traffic categories: KR6, KR4 and KR2 were adopted in accordance with [5, 8].
The thickness and layer systems for three selected traffic categories (KR6, KR4, KR2) adopted in the LCC analysis taking into account the catalog requirements are presented in Table 3, 4, 5.

Table 4 The list of layers thicknesses of flexible and rigid pavements for KR4 traffic category, after [5,6]

The flexible pavement with asphalt wearing course and base course with the unbound aggregate (cm)		**The rigid pavement** with Portland Cement Concrete slab in the wearing course and base course with mixture treated by hydraulic binder (cm)	
Medium traffic - traffic category KR4			
2.5 – 7.3 mln axles of 100 kN during the design period of 30 years		**6.39 – 15.99 mln axles of 100 kN during the design period of 30 years**	
4 cm	The wearing course layer of asphalt mixture	23 cm	The wearing course layer – PCC with dowels
6 cm	The binder course layer of asphalt mixture	-	The slippery layer: geotextile
10 cm	The base course layer of asphalt concrete	20 cm	The base course layer of aggregate mixture bound with a hydraulic binder C5/6
20 cm	The sub-base layer of unbound aggregate mixture	15 cm	The subbase course layer of aggregate mixture bound with a hydraulic binder C3/4
15 cm	The sub-base layer of aggregate mixture bound with hydraulic binder	20 cm	Capping layer of unbound aggregate mixture
20 cm	Capping layer of unbound aggregate mixture	25 cm	Improved subgrade stabilized with hydraulic binder or lime
25 cm	Improved subgrade stabilized with hydraulic binder or lime	79 cm	Subgrade
75 cm	Subgrade		

Table 5 The list of layers thicknesses of flexible and rigid pavements for KR2 traffic categories, after [5, 6]

The flexible pavement with asphalt wearing course and base course with the unbound aggregate (cm)		**The rigid pavement** with Portland Cement Concrete slab in the wearing course and base course with mixture treated by hydraulic binder (cm)	
Light traffic - traffic category KR2			
0.09 – 0.5 mln axles of 100 kN during the design period of 30 years		**0.15 – 0.75 mln axles of 100 kN during the design period of 30 years**	
4 cm	The wearing course layer of asphalt mixture	24 cm	The wearing course layer – PCC with dowels
8 cm	The binder course layer of asphalt mixture	30 cm	The sub-base layer of unbound aggregate mixture
20 cm	The sub-base layer of unbound aggregate mixture	22 cm	Capping layer of unbound aggregate mixture
22 cm	Capping layer of unbound aggregate mixture	24 cm	Improved subgrade stabilized with hydraulic binder or lime
24 cm	Improved subgrade stabilized with hydraulic binder or lime	76 cm	Subgrade
54 cm	Subgrade		

4. The comparative analysis of LCC for flexible and rigid pavements

The LCC analysis presented in this article is carried out in accordance with the methodology described in [1]. The time horizon was defined for the purpose of the analysis - adopted for 30 years and then the cost components were determined. The costs discussed in the article were determined on the basis of expert knowledge, current price publications and market data.

In order to carry out the cost analysis, the following assumptions were made:

- initial expenses, i.e. acquisition costs, taking into account: trench excavation for the structure together with the preparation of the foundation, costs of loading, transporting and utilizing the material from the excavation,
- excavations are carried out in frost susceptibility soil with the transport of the excavated soil up to 3 km with the formation and leveling of slopes on the deposit,
- the calculation includes the costs of the implementation and maintenance of the thick-layered horizontal marking on the surfaces,
- costs of maintenance, including costs of carrying out the following works: for the PCC pavement - reconstruction of the horizontal marking with the removal of the old marking and priming the area, winter maintenance - snow removal by the plow with salt sprinkling - assumed 120 times in the season, repair costs of the accepted range and conducted with the assumed frequency,
- the pavement construction cost calculations were made for a road segment of a given traffic category (KR6, KR4, KR2) and an area of 10,000 m²,
- the calculated unit prices take into account the costs of purchasing materials – i.e. costs related to the transport to the place of installation,
- the average unit prices were determined on the basis of information contained in selected Polish price publications [9, 10, 11] and information from the Polish market and individual calculations,
- a discount rate of 1.75% was assumed.

Based on the experience of domestic and foreign entities managing the maintenance of road infrastructure, assuming that the analysed road surfaces work in similar climatic conditions, the following strategies for their maintenance were adopted.

1. For flexible pavement and heavy traffic category - KR6:

- the replacement of the wearing coarse layer - 100% of the structure wearing course layer after 10 and 20 years of use,
- the replacement of all asphalt layers - 100% of the asphalt layers after 30 years of use,
- the partial repairs of the pavement - 1% of the pavement area after 2, 3, 12, 13, 22, 23 years of use, 2% of the pavement area after 4, 14, 24 years of use, 3% of the pavement area after 5, 15, 25 years of use, 4% of the pavement area after 6, 16, 26 years of use, 5% of the pavement area after 7, 17 years of use, 10% of the pavement area after 8, 18, 28 years of use and 15% of the pavement area after 9, 19 and 29 years of use,
- leveling the pavement surface - 3% of the surface after 5, 15 and 25 years,
- maintenance of horizontal marking - 100% of the construction area of 5, 10, 15, 20, 25 and 30 years and 2.5% of construction after 7, 14, 21 and 28 years of use,
- winter maintenance: 120 times during the winter season for 30 years.

2. For rigid pavement and heavy traffic category - KR6:

- partial replacement of the PCC slabs with the base course (demolition of the pavement, profiling of the subgrade, conversion of concrete debris into useful material, reconstruction of the concrete surface) - 2.5% of the surface after 7, 14, 21 and 28 years of use,
- complete replacement of the pavement with the base course - 100% of the pavement structure after 30 years of use,
- crack sealing - 1% of the pavement area after 7, 14, 21 and 28 years of use,
- keeping the horizontal markings - 100% of the pavement surface area of 5, 10, 15, 20, 25 and 30 years and 25% of the structure after 3, 8, 13, 18, 23, 28 years of use,
- winter maintenance: 120 times during the winter season for 30 years.

Appropriate maintenance strategies were also adopted for traffic caregories KR4 and KR2.
The list of acquisition, maintenance and cumulative costs over 30 years for 1 m² of flexible and rigid pavement for the KR6, KR4 and KR2 traffic categories is given in Table 6.

Table 6. The comparison of initial expenses - purchase costs (including earthworks and horizontal markings) and total maintenance costs

The flexible pavement with asphalt wearing course and base course with the unbound aggregate			**The rigid pavement** with Portland Cement Concrete slab in the wearing course and base course with mixture treated with hydraulic binder		
The initial costs (road construction) in [PLN/m^2]	The maintenance costs for a period of 30 years in [PLN/m^2]	LCC (acquisition and maintenance over a period of 30 years) [PLN/m^2]	The initial costs (road construction) in [PLN/m^2]	The maintenance costs for a period of 30 years in [PLN/m^2]	LCC (acquisition and maintenance over a period of 30 years [PLN/m^2]
KR6					
355,39	1280,14	1635,53	345,71	1342,30	1688,01
KR4					
304,92	1067,72	1372,64	333,70	1148,27	1481,97
KR2					
200,04	559,15	759,19	270,60	833,16	1103,76

source: own study

For the flexible and rigid pavement as well as for traffic categories KR6 and KR4 (i.e. heavy and medium traffic), the total life cycle costs (i.e. the sum of acquisition and maintenance costs) are similar (Table 6, Figure 1). In each of these two cases, the total costs are slightly higher for the rigid pavement. A clear difference in the compared total lifecycle costs for both types of surface occurs for the KR2 category (i.e. the light traffic) - Table 6, Figure 1. The total cost of acquisition and maintenance over a 30-year of a rigid pavement is 45.4% higher than total cost for flexible pavement (Table 6, Figure 1).

According to research (Table 6) for the KR6 traffic category, the initial investment for the flexible pavement is higher than the initial investment for the rigid pavement. It should be emphasized, however, that concrete pavements require regular work related to maintaining expansion joints in a good technical condition. These treatments usually concern only a few percent of the boards surface. For asphalt surfaces, maintenance procedures are only carried out in the event of damage, and the wear layer should be replaced in accordance with the accepted maintenance scheme.

The conducted economic analysis shows that for all included traffic categories (KR6, KR4, KR2), slightly higher lifecycle costs for rigid pavement are observed (Figure 1).

The life cycle costs of road pavements are closely related to the length of their exploitation period, the scope and frequency of maintenance and repair activities, the maintenance standard of the road used by its manager and the function and importance of the road. However, it should be noted that the costs of maintaining flexible and rigid pavements for the traffic categories KR6, KR4 and KR2 in the longer term (e.g. 30 years) are significant in comparison with the costs of their purchase. They constitute over 70% of the total cycle costs of the construction life cycle (Figure 2).

The results of the LCC analysis, for selected traffic categories and two technologies for the construction of different type road pavements indicate that this method in practice should be one of the basic criteria for the selection of the optimal solution, i.e. an economically justified variant of undertaking the implementation.

5. Conclusions

The research and analyses carried out by the authors justify the formulation of the following statements and conclusions.

1. The use of LCC analysis at the concept stage, defining and designing the road pavement offers great opportunities to reduce costs throughout their life cycle. The problem, however, is obtaining reliable information regarding the operation costs and the surface removal. Currently, there are no uniform technical regulations in Poland on the recommended scenarios for road surface maintenance in the longer term. Therefore, a long-term experience of road managers and entities responsible for the maintenance of road infrastructure can be a valuable source of information on the scope and costs of maintenance and repair of pavement constructions. Taking into account their knowledge and experience at the design stage, performing and maintaining different types of surfaces, in accordance with certain standards and requirements, should ensure good functional features of the structure throughout the assumed lifetime.

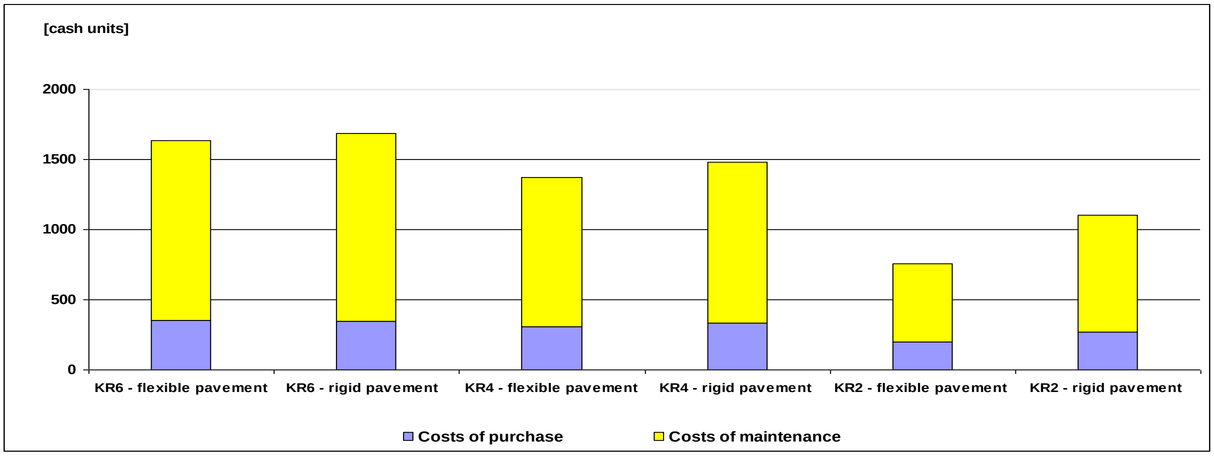

Fig. 1 Costs of purchase and maintenance for 30 years for flexible and rigid pavement, including KR6, KR4, KR2 traffic categories
source: own study

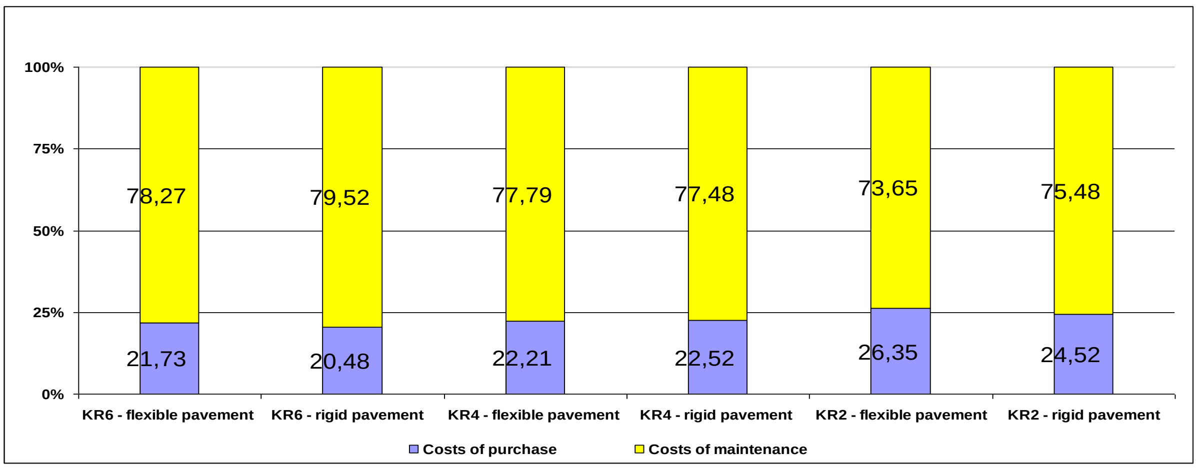

Fig. 2 Proportions of purchase and maintenance costs over a period of 30 years in the total life cycle cost for flexible and rigid pavement, including traffic categories KR6, KR4, KR2.
source: own study

2. An important element in the estimation of the road pavement life cycle costs is the precise definition of activities of various nature, which may have an impact on the reduction or increase of costs and determining the correlation between them. An important element of the LCC analysis is to determine the lifetime of the surface (e.g. 30 years) and the amount of the discount rate. Input data formulated in this way can be processed using a specific calculation model. The obtained results should be verified.
3. The proposed approach to the selection of the optimal variant in the road pavement implementation, fully fits in the idea of environmental protection and sustainable development of the economy promoted in the EU. In each of the analysed cases, the performance and maintenance of a flexible pavement in the long run is associated with a smaller investor's expenses. Particular savings in the long term are visible for the KR2 light traffic category. The total cost of purchase and maintenance of a rigid pavement in 30 years is 45.4% higher than the cost of maintaining flexible pavement during this period.
4. According to [1] the life cycle cost estimation is the most effective at the early stage of product design. There is the possibility of effective optimization of the solution. It is also recommended to update information in the next phases of the life cycle in order to identify areas that generate significant costs during the maintenance phase.
5. The presented analysis concerns only the life cycle costs of the pavement. However, it should be emphasized that the analysis should be extended by LCA (Life Cycle Assessment). According to the standard [12] the life cycle is defined as "subsequent and related stages of the product, from obtaining or producing raw material from natural resources to its final disposal". An important activity of the LCA analysis is to conduct a detailed balance of the use of materials and energy. Performing such a study contributes to reducing the negative impact of the product on the

environment at the stage of manufacturing, incorporation and use, but also measurable financial savings by increasing the efficiency of energy and raw materials use [13]. Therefore, the LCC analysis combined with LCA will allow to indicate unambiguously which of the road and pavement presented construction technologies is the optimal choice in terms of costs and environmental impact. Such analysis is the direction of further research carried out by the authors.

6. Among the fundamental practical problems related to defining the life cycle costs of road pavements, it should be mentioned the concentration of contracting parties only at the initial cost related to their performance, without taking into account the costs associated with their maintenance. Documents have been developed in many countries around the world, indicating methods for calculating life cycle costs. These experiences can be a benchmark for defining the methodology of conducting LCC analysis for road infrastructure in Poland.

7. Despite numerous limitations (including determination of individual components of costs, requires multidisciplinary and extensive field, laboratory and simulation research at the national and regional level), the LCC analysis can be applied to assess the effectiveness of various variants of acquisition of new road pavement or modernization of existing ones. It provides transparent information about the possible consequences of the solutions under consideration, taking into account the durability period and the parameter of the pavement's reliability.

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Tunnels between continents

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Abstract

Future transport may have to reduce the use of energy, especially the use of fossil fuels, this points towards reduction of transport by ships, aeroplanes and cars.

Trains are a well documented way of transporting large volumes of goods as well as persons and it is assumed that the total use of energy would be very much lower than the earlier alternatives.

Furthermore, the savings of surface area, airports and roads, would be considerable, the reduction of noise as well.

Train connections across oceans and across wide bays and lakes, presents interesting possibilities of making present and future transport more efficient

By this paper the author hopes to raise interest for these promising and challenging possibilities.

The proposed design of the tunnels may be seen on internet link below, page 10, the tunnel construction and challenges will be discussed in broad terms in this paper.

Keywords: Tunnel, continents, crossing, deep sea, MAGLEV

1. Introduction

Oceans are a great obstacle to transport of both goods and people and may only be crossed by aeroplanes and ships.

Aeroplanes provide fast crossings over long distances, but as environmental effects are becoming more important a search for transport alternatives will be aimed at increasingly protecting the environment.

Airports require large areas to operate planes and as populations increase so does the required areas.

The noise, pollution and use of fossil fuels are adding to the problems of air transport and it seems the lobbying against air transport is constantly increasing.

One promising development in air transport may be electrical engines in large passenger planes in future.

Ships are using fossil fuels and represent serious pollution problems and transport across the oceans is slow.

This paper attempts to present an alternative to cross the oceans and wide bays by a system of three tunnels located below sea level, perhaps 200-300 meters, and using MAGLEV trains with speed as high as practically possible at the time.

The reasons for three tunnels are requirements for the tunnels to be “forever open”

One tunnel closed the other two runs as normal as outlined in several EU research projects.

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2. Proposed concept

Figure 1. gives an idea of possible crossings globally, this is of course only to illustrate the general idea.

A detailed study of a few places for crossings would be interesting, but political reactions might however complicate such studies.

Fig. 1 Possible areas of ocean crossings

In Figure 2. the tunnel arrangement is shown with some short comments.

The three tunnels are connected by crossover tunnels located at intervals, these tunnels will serve as escape possibilities and also contain the nuclear power stations providing necessary power for the MAGLEV trains.

The crossover tunnels also have housings for the thrusters keeping the tunnels in the position in the sea.

Reduced air pressure in the tunnels will be beneficial, these and a large number of other issues have to be studied later.

The position of the tunnels below sea level will be defined by considering effects by currents and waves, lengths of anchors from biggest ships, and any other activity deemed important.

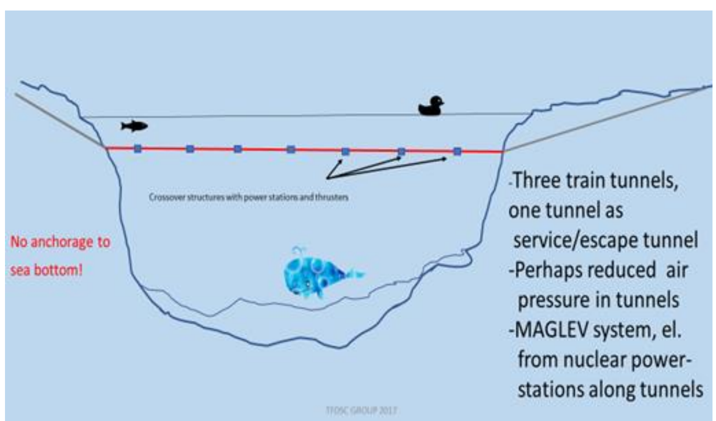

Fig.2 Principle of deep sea crossing

3. The submerged floating tunnel (sft)

The Høgsfjord Project, Norway, was a study of a concrete crossing of a fjord on the west coast and included extensive research and development projects for about 15 years.

This was a completely new type of structure and called for both national and international consulting work and other countries also became involved in this new structure, especially Japan, Italy and China.

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The Høgsfjord project was initiated and carried out by The Norwegian Public Road Administration, Road Research Laboratory and was finalized by complete tender documents on four alternatives approved by the Norwegian Public Roads Administration.

These alternatives were developed together with four Norwegian contractors and a large number og consultants and contained detailed designs of the SFT.'

The project was not executed due to political and financial reasons.

These studies and projects are the background for the tunnel system proposed in this paper, and the principle of SFT may be seen in Fig.4.

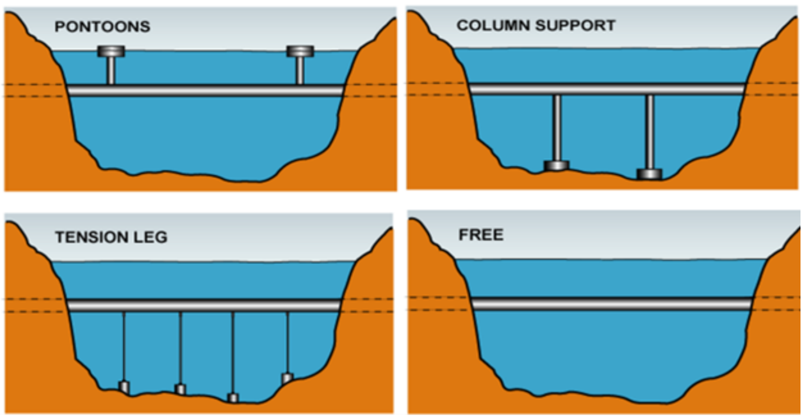

Fig.4 The four alternatives for Submerged Floating Tunnels (SFT)

4. The proposed concept for deep sea crossings

In Fig 5 the system of three tunnels for MAGLEV trains is shown.
The tunnels are identical, and trains may operate in all three while one tunnel will act as escape or maintenance possibility, this will give increased possibility for two tunnels in operation at all time and meeting the EU regulation for "Forever Open Roads".
The structure is kept in the desired position by thruster arrangements as shown in Fig.5, such systems have proven to be reliable for many years, notably for ships and oil platforms.
As trains approach the thrusters will adjust to the increased weight and keep the structure at the predetermined depth and opposite reaction when trains have past.
This system will of course require backups and extra capacity and extensive research and full scale testing over several years and may be the most important challenge of the whole project.

Bearing in mind the long experience with thruster systems, there is no apparent reason for this to not to be possible.

Electricity for MAGLEV and many other systems and installations may be produced by nuclear power stations located at intervals along the tunnels.
Nuclear power stations have been operated in ships and submarines for many years and safety in operation is proven to be very good and there should be no reason not to use such an arrangement.

Looking at the tunnels in Fig. 5 a large number of questions come to mind and a few are listed below and a short comment is attached where it is possible.

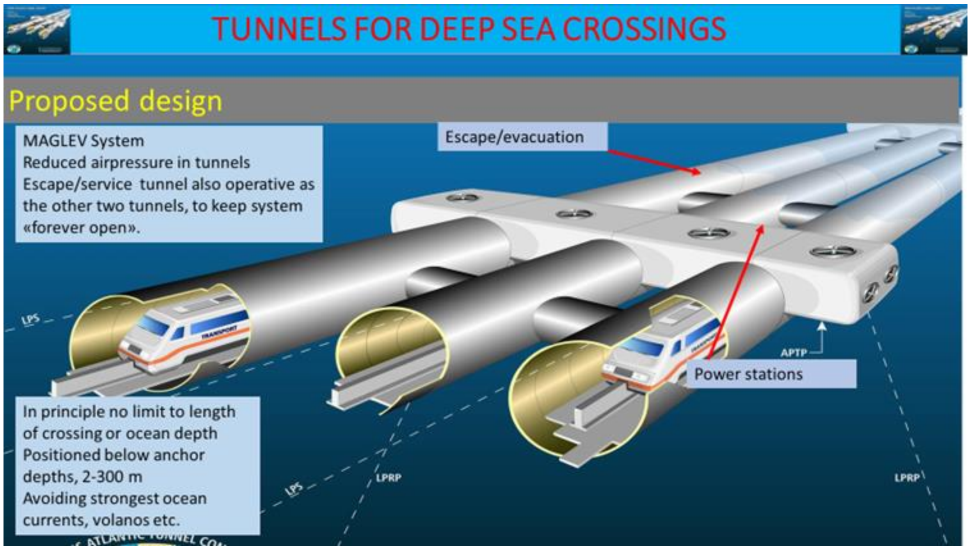

Fig 5 The proposed system for deep sea crossing

5. A brief discussion

- Why should we want such a system?
  It is assumed that a lot of sea and air transport would be considerably reduced resulting in less use of fossil fuels and reduction of pollution.
  Trains also will have stations within cities underground and take little space on the surface, perhaps areas for present day transport may be free for other developments.
  Air transport creates noise and this will be greatly reduced although electric planes will undoubtedly improve this situation in future.
- Can such a system be safe?
  Nuclear powerstations along the tunnels may cause many worries for a lot of people and if there is a better alternative it should be used.
  Whether it is possible to use land based powerstations and feed electricity enough or very long tunnels is not known to the author, perhaps other possibilities of producing power will come in future.

Safety of complex structures and for example aeroplanes have increased as the complexities of these objects have increased and safety at present is very impressive indeed.

Safety of the proposed tunnel system will depend on a large number of factors ranging from quality and integrety of persons in research teams, sufficient financing, leadership and many other factors that will vary with time. The final approval of such a system will be a real challenge, perhaps on the level of the Appollo Project.

But the problems and challenges should not stop anybody not to think about the possibilities such a system could offer to global transport.

A short list of some topics of safety could be:

- Explosion, accident
- Terrorism, all types, outside-inside
- Fire
- Nuclear power station malfunction, powercut
- Malfunction of positioning systems
- Water ingress, local or on a large scale
- Noise problems inside tunnels

- Airpressure problems, inside-outside trains
- Trainstation closed onshore
- Earthquakes
- Tsunamies
- Volcanos
- Change in water densities, temperatures
- Change in sea currents
- Collision with submarines

Other challenges might be:

- Financing system, agreements, guaranties
- Political situation on both landings change
- War situations
- Funds for continuos operation and maintenance
- Environmental impacts on marine life, noise and vibrations
- Any type of pollution from structure
- Impact on global material production during construction period, steel, concrete, aluminium, other metals and materials.
- Public do not want to use the trains, risk too big
- Keeping test periods sufficiently long, pressure on starting normal operation
- Airpressure from trains used for some useful purpose
- Dissipation of airpressure approaching stations. (Used to push the other train in opposite direction?
- May be start this operation long before train arrives at end station)?
- Use MAGLEV`s ability to negotiate steep gradients near station, not necessary to construct large protecting structures against ships and anchor problems.

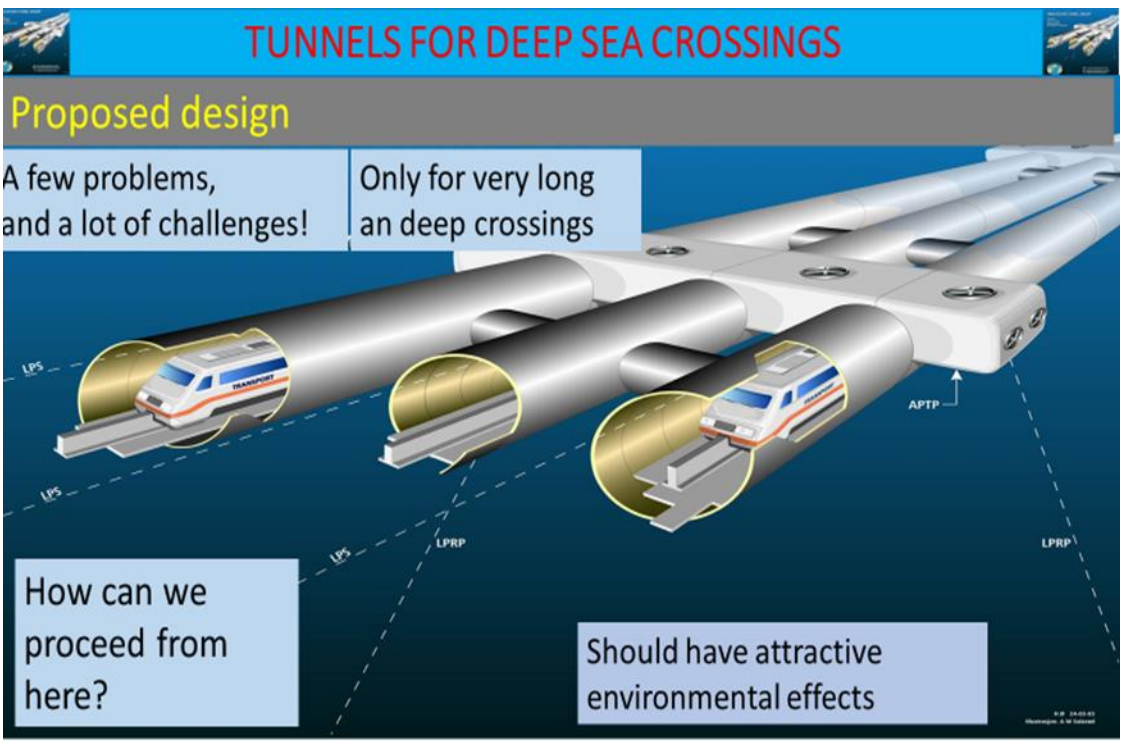

Fig. 6 One alternative and there may be many other alternatives

6. Acknowledgement

I would like to thank the following persons for taking an interest and discussing this concept with me, giving good advice and criticisms being of great help and encouragement.

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- Kaare Flaate, former Director of Road Research Laboratory, Norway
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7. References

No references, proposed tunnel structure is authors idea.

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Use of a 3D scanner for imaging concrete sample surfaces abraded with the ASTM C 1138 method

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Abstract

In the case of most concrete constructions, aggression caused by abrasion is not the basic type of destructive environmental impact. However, in the case of certain structures, such as hydraulic constructions, it is indeed a basic impact. In addition to corrosion, the largest proportion in the general destruction of concrete hydro structures is made up by erosion from debris, wind and ice. In tests of abrasive wear on concrete, the so-called underwater method, which is described in detail in the American Standard ASTM C 1138. The abrasive wear of a concrete sample is the result of the surface impact of test steel beads placed in water and set in motion by means of a stirrer. The result of the test is the average sample area consumption, calculated using the weight loss of the concrete sample during the test. However, this method does not allow for an accurate display of the sample surface. There is no possibility of determining the size of the maximum wear of depth.

In surface imaging tests of concrete samples subjected to abrasion, in the device using the ASTM C 1138 method, an Atom Triple Scan GOM optical scanner was installed on an industrial robot with an integrated rotary table. Thanks to the use of a 3D scanner, it was possible to compile a map of the concrete sample surfaces. The scanner software allowed cross profiles to be made at any place in the samples tested. Thanks to the exact depiction of the abraded concrete surfaces used, it is possible to properly assess the concrete used in hydraulic constructions and as a repair material.

Keywords: abrasion resistance; 3D scanner; surface damage; hydrotechnical construction; underwater method

1. Introduction

Besides static and dynamic loads, engineering objects and structures are exposed to environmental actions, which can have significant effects on theirdurability and safety in use. The intensity of these direct actions is the basis for categorization of the environment, taking into consideration, among others: the results of cyclic freezing and thawing of the concrete, the influence of carbon dioxide, the action of the sodium chloride used for de-icing or contained in sea water, as well as the chemical corrosion of concrete, which leads to the destruction of the cover of the reinforcing steel; and abrasive wearing of the surfaces of concrete elements and structures. Hydrotechnical concrete structures are exposed to, among other things, the erosive action of the environment caused by solid particles transported by water (water erosion) and air (wind erosion). The concrete for making hydrotechnical structures, besides having the specified compressive strength, should also have the highest possible wear resistance. Abrasive wearing caused by river or sea debris, transported by water, is different from the abrasion of road pavements or airfield plates [1].

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In the investigation of the abrasive wear of concrete or other materials, it is necessary to select a method which can best reflect the abrasion of the material in the natural environment. The most often used method for testing the abrasion of concrete in EU countries, is Boehme's disk, described in EN 14157 [2]. However, this method does not reflect the mechanism of concrete wear, as observed in hydrotechnical structures [3-5]. The most often used method for testing the wear resistance of concrete in hydrotechnical structures is an American method: the so-called underwater method, described in ASTM C1138 [6]. The underwater method is intended for testing the wear resistance of concrete surfaces in hydrotechnical structures. It simulates the conditions of concrete wear under abrasion, which is present on the surfaces of hydrotechnical structures, as a result of the movement of debris transported by water. The method consists of the wearing of the surface of a concrete specimen, placed at the bottom of a steel cylinder. The abrasives are steel balls of various diameters, placed in the water in which the specimen is immersed. The balls are moved by the action of a special stirrer. The testing of concrete abrasion with the underwater method is described in detail in section 2.2, below.

The use of the underwater method makes it possible to determine the average abrasive wearing of concrete, though it is not possible to determine the maximum depth of the losses, in this manner. To determine maximum losses, a 3D scanner was employed after wearing. The scanner was also used for preparing a map of the wearing on the abraded surfaces of the specimens. This map enabled a better prognosis of abrasive wear, particularly in the context of designing hydrotechnical reinforced concretes.

2. Materials and methods

2.1. Materials

One cubic meter of concrete was prepared using Portland cement CEM I 42.5 R, with a density of 3.1 kg/m^3 (400 kg), river sand up to 2 mm (593 kg), natural gravel aggregate with a maximum grain diameter of 16 mm and a density of 2.64 kg/m^3 (1110 kg), polycarboxylate superplasticizer (8 kg) and a viscosity modifying admixture (4 kg).

The water to cement ratio of the concrete was 0.4. The compressive strength of the concrete, after 28 days of curing in water, was 54.45 MPa.

2.2. Abrasion testing

The abrasion tests were conducted using the underwater method, according to ASTM C1138 [6]. The scheme of the testing equipment used in the underwater method is presented in Fig. 1. Cylinder specimens with heights of 100 ± 13 mm and diameters of about 6 mm, were placed in the testing container (with the tested surface facing upwards), which was a steel pipe with an internal diameter of 305 ± 6 mm and a height of 450 ± 25 mm, with a tightly fitted base. A rotating machine, such as a drill or similar machine, was used as the stirrer, making abrasive movements in a rotational-vertical way at the bottom, with a speed of 1200 ± 100 rotations per min.

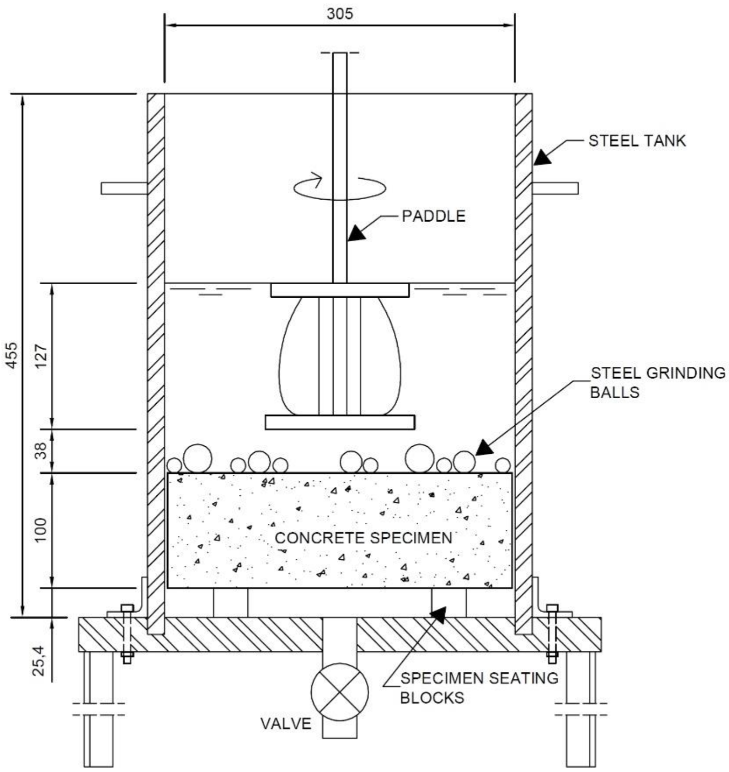

Fig. 1. The scheme of test apparatus according to ASTM C 1138 [6].

Seventy balls made of chrome steel, with nominal diameters between 0,5" and 1,0", were used as an abrasive. After weighing, the balls were placed on the surface of the specimen, with the system then being immersed in water up to a level of 165 ± 5 mm. A stirrer with a specific shape was then run with the given speed. According to the requirements of the standard [6], the specimen should be worn for at least 3 cycles of 12 hours each. In the investigation presented here, the specimens were worn for 72 hours (6 cycles of 12 hours each). The specimens were weighed after each cycle, after being rinsed and dried superficially .

The calculation of the wearing losses was performed by determination of the average depth of wearing, at the end of each period ADA_t [m]:

$$ADA_t = \frac{VL_t}{A} \tag{1}$$

This was the ratio of the volume of the material lost in a given period, VL_t [m^3], to the surface area of the specimen A [m^2].

In the tests presented here, the specimens were abraded after 28 and 56 days of curing, with 3 specimens for each curing time.

2.3. Imaging of the surfaces of tested specimens

An Atos Triple Scan optical scanner, produced by the GOM Company, was used for imaging the specimen surfaces, after the abrasion tests. The scanner was installed on an industrial robot with an integrated rotating table (Fig. 2).

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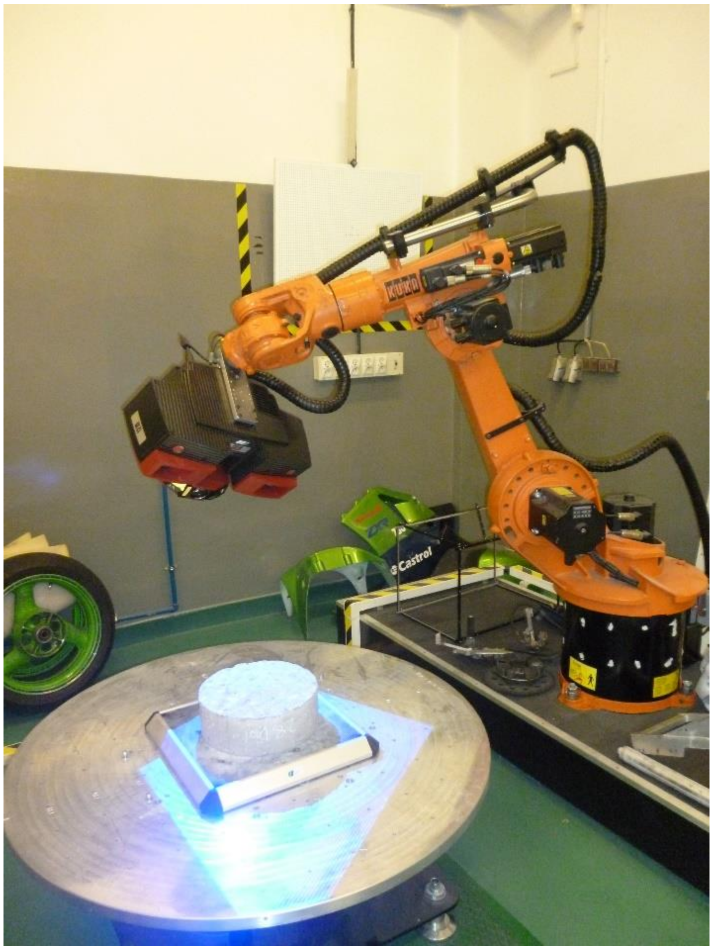

Fig. 2. Industrial robot with Atos Triple Scan optical scanner.

After preparing the head movements, measurement was conducted in the automatic cycle, thus enabling the best repeatability of the scanning conditions (positioning of the head and external lighting). The head was equipped with a structural light emitter and a two-camera optical system. This made it possible to scan the surface as well as to measure the reference points (markers) photogrammetrically, which enables joining of the scans from different directions. The specimen during scanning is presented in Fig. 3 (with visible markers on the specimen surface). LED technology and the use of narrowband (blue) filters enabled a significant reduction in the influence of infrared radiation.

The average time for measuring one specimen in the automatic cycle was about 1 minute and covered measurements taken from four directions, selected by the operator. ATOS Professional V8.0 software was used for the data processing.

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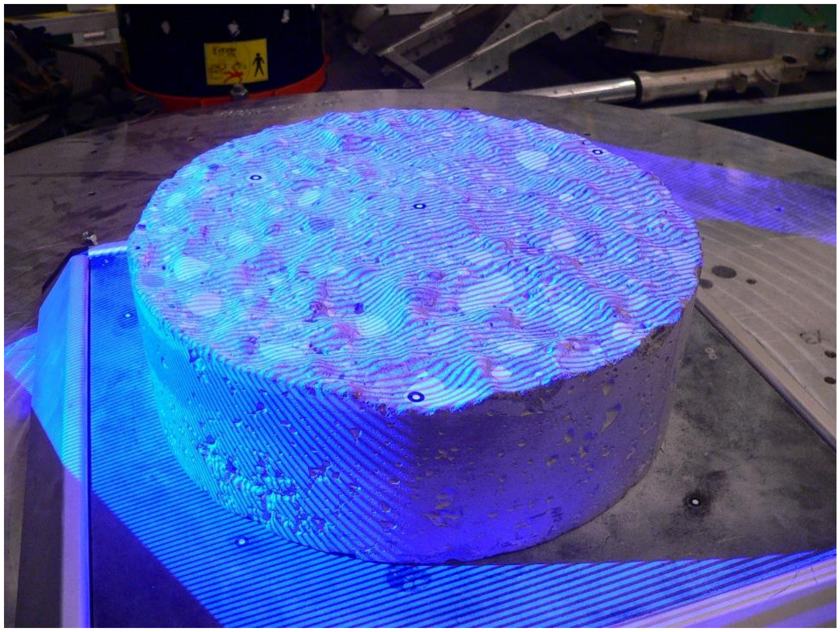

Fig. 3. Concrete specimen during scanning.

3. Results and discussion

The average value for the depth of abrasion loss (depth of wear – DOW) is the final result of the testing of abrasion using the underwater method. The use of a 3D scanner enables, not only the determination of the average value of the DOW, but also its maximum value, which is very important in the case of materials with components of varying hardness. This is particularly significant for reinforced concretes, where information on the DOW_{max} affects estimation of the thickness of the concrete cover of the reinforcement. The results of measurements for the specimens tested are presented in Table 1. The software used, also enabled development of a spatial image of the surface of the worn concrete, as well as a very accurate map of the losses and wearing profiles in all areas of the specimen surface (Fig. 4). Such information on surface wearing, makes it possible to design better structural and repair concretes, in consideration of their required abrasion resistance. An additional advantage is the fact that the time of measurement, after positioning the scanner, is only about one minute. In the case of the underwater method, the weighing of the specimens on a hydrostatic balance is very labour-consuming. As a comparison, in 2009 the authors reported on the results of imaging of concrete specimens worn using the underwater method, with the use of 2D scanning [7]. A coordinate testing machine, ECLIPSE CNC, enabling accurate imaging of the surfaces of the specimens tested, was used for description of the wear surface of the concretes tested. A model of the elements examined was created with I-DEAS 10.0 software, which allows writing of the data in VDA format.

Table 1. Results of abrasion testing of the concrete.

Underwater method		3D Scan			
ADA_t [mm]	average volume [cm^3]	ADA_t [mm]	average volume [cm^3]	DOW_{min} [mm]	DOW_{max} [mm]
97.5	6760	98.0	6843	4.71	11.14

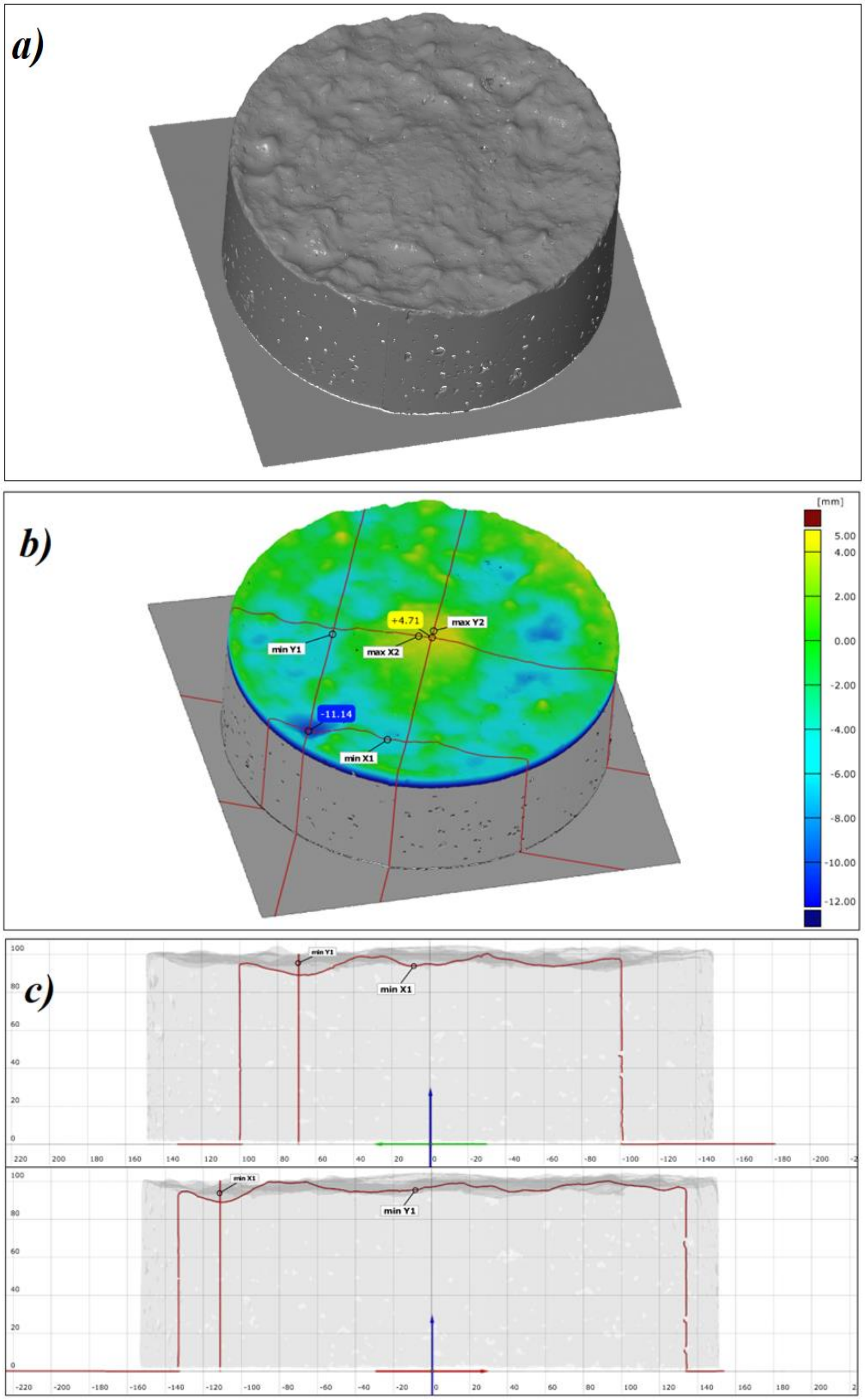

Fig. 4. Results of imaging of the surface of a specimen worn by the underwater method using a 3D scanner: a) specimen image; b) spatial map of the worn surface; c) example of the sections done at the point of DOW_{max}.

Gauging point calibration and the definition of the reference system and safety planes were conducted before measurement. HOLOS-NT measuring software, utilizing the previously created element model, was used to measure the surface of the specimens. With more than 6000 measurements conducted for each specimen, the resultant time taken for scanning of the surface of the specimens was several hours.

The 3D surface imaging made it possible to obtain very accurate projections of the surface; the accuracy was over a dozen micrometers. The use of ATOS Professional V8.0 software made it possible to conduct sections in any place of the specimen (Fig. 4c).

4. Summary

Imaging of the surfaces of worn concrete specimens with a 3D scanner, makes it possible to obtain very accurate descriptions of any part of specimen surfaces. The use of professional software makes it possible to develop spatial surface maps of concrete abrasions and profiles of specimen geometry, in any place. In this way, it is possible to more effectively design repair materials and structural concretes for hydraulic objects.

Using the underwater method with a hydrostatic balance, according to ASTM C1138, and 3D scanners, also significantly shortens the measurement time of the abrasions of specimens.,

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Variable Refrigerant Flow (VRF) Systems in the South-Eastern United States

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Abstract

This research study endeavored to evaluate the use of VRF systems in the South-Eastern United States. More specifically, to understand and analyze why these systems have not been popular in this part of the world. The VRF technology, invented by the Japanese, has been around for more than 30 years. Europe and Asia-Pacific regions are two biggest consumers of this technology with their combined market share of 65% of the global market. The research aimed to get answers to three basic questions (1) What is the condition of commercial VRF market in the South-Eastern United States? (2) Why have VRF Systems not been popular in the U.S.? and (3) What is the future path for this technology in the U.S.? A survey questionnaire was carefully developed to understand and analyze -What is the extent of penetration of VRF technology; What is the level of awareness about this technology; and what types of projects are being preferred for VRF systems. The results of this survey were evaluated along with other literature including reports from analysts and interviews of leading VRF manufacturers.

Keywords: VRF Systems, HVAC, Energy Efficient Air Conditioning Systems, Refrigerant

Introduction

Air-Conditioning systems have been a part of the built environment since pre-historic times. The basic concept behind air conditioning is said to have been applied in ancient Egypt, where reeds were hung in windows and were moistened with trickling water. The evaporation of water cooled the air blowing through the window. Use of modern air-conditioning started in the 19th century and since then, the technology has evolved to a great extent. In 1902, the first modern electrical air conditioning unit was invented by Willis Carrier in Buffalo, New York. (Wikipedia)

Air conditioning and refrigeration are provided through the removal of heat. Heat can be removed through radiation, convection, or conduction. Refrigeration conduction media such as water, air, ice, and chemicals are referred to as refrigerants. Similarly, in colder climates, heating can be achieved by transfer of heat by convection, conduction, or radiation. Before the invention of modern HVAC systems, two most popular systems used for HVAC were (and in the U.S., still are) – Direct Expansion or DX systems for residential uses and Chilled Water based Systems for commercial and industrial uses. Traditionally, heating systems were kept separate from the cooling systems and were based on use of hot water, steam or heating coil in a loop throughout the buildings or houses. However, with the help of technological advancements, we now use systems that provide heating or cooling from the same system, based on the zonal requirements. These systems have been more popular and today, we see most of the residential and commercial market using DX or Chilled Water based systems with air circulated through ducts.

Chilled Water based systems with ducted air-flow have been the most common HVAC systems used in commercial projects throughout the world. The technology for these systems was first developed in the United States and later adopted by the

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rest of the world. However, with invention of modern HVAC systems such as VRF, most of Asia-Pacific and Europe started realizing their advantages. According to a report by Pacific Northwest National Laboratory (Thornton & Wagner, Dec 2012) VRF had about 24% of the global commercial air conditioning market, and over 35% market share in China, India, the European Union, and Eastern Europe. In 2015, the VRF market in APAC and Europe combined had a share of close to 65% (more than $7 billion in total $11 billion) of global market (Markets&Markets, 2016). Hence, we can say that, today, VRF system is the most popular HVAC system for commercial use in developing parts of the world like China and India as well as developed parts like Europe and Japan. United States, on the other hand, in year 2012 (GSA, 2012) had VRF systems serving only 3% of its office spaces which marginally increased to 4% in 2013 and remained same for 2014. Their share in the global VRF market in year 2015 was just over 11% at $1.27 billion (Markets&Markets, 2016). The U.S. HVAC market, obviously, did not adopt this technology and has still been using the traditional systems as the preferred technology for its HVAC needs.

Research Objective

Commercial buildings account for approximately 40% of the energy bills and 40% of the carbon dioxide emissions in the United States (USDOE 2012a). Even today, these figures are in the range of 37% to 40%. About a third of commercial building energy usage is for heating, cooling and ventilation (GSA 2012). Retail sales of electricity in last 4 years (2013 to 2016) state that Commercial sector has consumed about 1.35 to 1.36 million KWH every year (US Energy Information Administration). Based on this data, we can understand how important it is for the U.S. to implement energy efficient HVAC systems, such as VRF, in this sector. The objective of this study is to understand VRF Systems market in the U.S., find out the reasons behind its slow growth and explore the possibilities of this technology being popular in next few years with focus on commercial buildings sector in the South-Eastern United States.

Background

Before we discuss further about use of VRF system in the United States, let us first understand what VRF systems are and what are their advantages and limitations over the conventional systems.

<u>History of VRF:</u>

VRF Systems have been in the global market for last 30 years. Daikin Industries Ltd. (Japan) is considered as one of the important players in the development of VRF systems market. The company invented variable refrigerant volume (VRV™) systems in 1982 in Japan. However, the real advancement in this technology was made in 1990 when modularity and simultaneous heating and cooling were made possible (Daikin). It was only in the mid-2000s, however, that these systems were ready to perform at extreme hot and cold climates as well as control humidity. During this period of 15 years, other Japanese manufacturers such as Toshiba, Mitsubishi, Panasonic etc. developed this technology and started marketing their products globally.

In her article for the ES Magazine in February 2015, Marcia Karr of WSU mentioned that, this variable refrigerant capacity technology was first conceived in the United States. However, the patent was allowed to expire when they were not successful in achieving their goal. Japanese manufacturers bought the patent and perfected the concept and introduced the ductless mini split system to the HVAC industry. (Karr, 2015)

<u>What is the Technology?</u>

VRF HVAC systems include two major parts, a compressor unit and multiple indoor fan coil units. The compressor unit, typically located on the roof, cools and heats refrigerant connected through piping to condition the building. The compressor units are typically air cooled. Sometimes water-cooled units are used and are connected to a cooling tower and boiler. In most installations in the United States, these systems are capable of simultaneously cooling some zones, and heating others. These systems can recover heat from spaces being cooled for use in spaces being heated and vice versa. The compressor unit uses variable refrigerant flow and is controlled by a variable-speed drive, which may operate more efficiently than conventional compressors of similar size. The complexity of the variable refrigerant flow compressor and controls results in significantly more expensive compressor units than comparable conventional systems.

Required outside air must be delivered to the space through another mechanism. This is usually done with a separate HVAC unit, commonly called a dedicated outside air system (DOAS). These units often include energy recovery from the exhaust air to the incoming outside air, including pre-cooling the outside air when it is hot and pre-heating the outside air when it is cold, and may also recover energy used to dehumidify or humidify the outside air. (Thornton & Wagner, 2012)

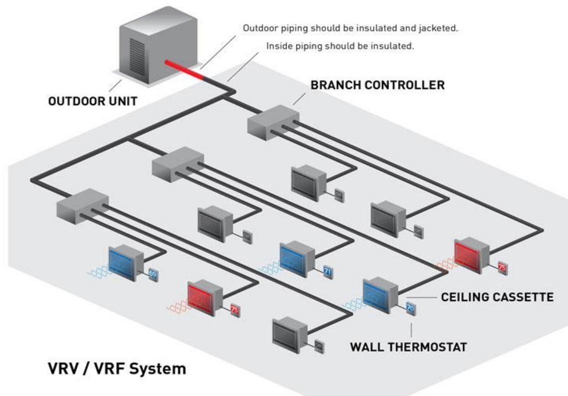

Figure 1: Schematic drawing of VRF system showing single outdoor unit with multiple indoor units. (ACHR News)

System Configuration:

Indoor units range in size from less than 1 ton up to approximately 8 tons. These units can be a fan coil type; either ducted or non-ducted, an exposed ceiling mounted unit, a concealed ceiling mounted unit or a wall mounted unit. Outdoor units range in size from approximately 5 tons for a single unit, up to 30 tons for multiple units connected together to form one single larger tonnage unit. Example: (2) 5-ton units can be connected to form a single 10-ton unit or an 8-ton unit can be connected to a 10-ton unit to yield a total tonnage of 18 tons and an 8-ton unit can be combined with a 10-ton unit and another 10-ton unit to yield a total tonnage of 28 tons. While being configured from multiple units and requiring separate power connections, the resulting "combined" unit is considered a single unit. (R&W Engineering)

Refrigerants:

Even though the invention of refrigerant happened in early 1900s, these refrigerants were mostly toxic and flammable. The first non-flammable, non-toxic chlorofluorocarbon gas, (Freon™) was created by Thomas Midgley, Jr., in 1928. The blend most used in direct-expansion home and building comfort cooling is an HCFC known as chlorodifluoromethane (R-22). However, it was only in the 1990s, ozone depleting properties of these CFC gases were discovered. In mid 1990s, Germany, amongst other EU nations, was the first to ban this refrigerant followed by the U.K. in year 2000 (Wikipedia). But the U.S. continued using it for several years. Only in 2011 did the E.P.A. (EPA – Montreal Protocol) finally decide in favor of the ozone and climate-safe refrigerant for U.S. manufacture. Modern refrigerants such as R-717, R-744 (CO_2), and R-32 etc. have been developed to be more environmentally safe.

Advantages of VRF system:

It is important to understand how VRF technology can be used for higher energy savings. However, this system has other advantages which, when compared with conventional systems, make VRF a better option for almost all types of applications. Below are some prominent features of VRF system…

1. **Energy Efficiency:**
   One of the first research publications on VRF Technology by William Goetzler (Goetzler, 2007) for ASHRAE Journal mentions that VRF Systems use about 30% to 40% less energy than comparable chilled water systems. Higher energy efficiency of these systems has, since then, been a topic of interest for many researchers. In last 10 years (2007-2017) several independent analyses have been carried out and almost all of them, including GSA, have confirmed this data.

In 2013, a comparative analysis of VRF systems as alternative for conventional HVAC systems was presented (Jaesuk Park, Georgia Tech, 2013) This study investigated two aspects of VRF systems: efficient energy performance and economic benefits. VRF systems reduce energy consumption for heating and cooling by an average of 39.9% compared to conventional HVAC systems.

2. **Installation Advantages:**
VRF system components are modular, small and lightweight compared to conventional HVAC system components. They are typically installed without the use of a crane, saving substantially on installation cost. The unit modularity supports building a system over time to serve floors as a building is occupied. The low weight can reduce the need for structural reinforcement to support more massive equipment. The compressor units are typically installed outdoors and do not need a machine room or mechanical penthouse (Goetzler, 2007 as cited in Thornton & Wagner, GSA, 2012).
3. **Space Saving:**
VRF systems have limited space requirements, particularly for the distribution system inside the building. Transferring heat through refrigerant piping requires a lot less space than ductwork. This makes VRF systems well suited to retrofits, particularly historic buildings that may not have any ductwork or cooling. In new buildings, the low space requirement can result in reduced floor-to-floor height, providing initial cost savings (Thornton & Wagner, GSA, 2012)
Jared Edwards, CEO of HES, Dallas stated in his article for CES Magazine in August 2014, that "one of the most valuable features of VRF systems is their ability to be low profile and ductless". Moreover, most manufacturers can compact 4 tons of cooling in one single cassette unit which can be placed in a 2x2 lay-in grid. This allows us to obtain the cooling capacity of a data or equipment room by using space of only a few ceiling tiles. To reduce the outdoor footprint, most manufacturers can provide a network of up to 64 indoor units connected to one outdoor unit.
4. **Comfort:**
The most prominent advantage of VRF systems is their ability to provide heating and cooling simultaneously. This can be achieved by using the heat recovery type VRF system. The buildings can now recover wasted heat by capturing the heat normally discharged to the atmosphere in cooling mode and moving that energy to the zones that need heat.
5. **Control:**
VRF systems incorporate sophisticated controls and automation; control of the complex refrigerant system requires this. A control system is set up to communicate among all components and can operate as an energy management system within the network of systems. The control system can network with the rest of the building with open protocols such as BACnet and LONworks. Providing a comparable level of control with conventional equipment would add additional cost to those systems. As an option, the refrigerant flow to each fan coil unit can be automatically measured, allowing the energy usage of the system to be allocated to each tenant. (Thornton & Wagner, GSA, 2012)
6. **Maintenance:**
Similar to conventional systems, regular maintenance of VRF systems consists of changing filters and cleaning coils for the fan coil units. Maintenance of the compressor unit is minimal, and there will be significant maintenance savings for this part of the system compared to chilled water and hot water plant equipment. This has great potential in lowering the Life Cycle Costs of the systems.
7. **Other significant features:**
In addition to the advantages mentioned above, flexibility and modularity, Lower installation time, quiet operation, LEED certification are other significant features due to which a building owner gets convinced. .

<u>Limitations of VRF system:</u>

1. **Refrigerant:**
Quantity - In the U.S., ANSI/ASHRAE Standard 15 limits the quantity of refrigerant per thousand cubic feet of interior volume beyond which acute toxicity is expected. Those designing VRF/VRV systems should verify the amount of refrigerant that could be lost due a leak and the smallest space into which this refrigerant could accumulate are in compliance with this standard.
Leaks - A leak in a VRF system is a serious and potentially dangerous matter. VRF/VRV systems contain much more refrigerant compared to hydronic systems. Large refrigerant leaks can require immediate evacuation of the building and possible intervention of Hazmat teams. (Seigenthaler, 2016) All leading manufacturers of VRF systems now offer advanced leak detection technology.

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2. **Fresh Air:**
   Every VRF System needs to have the ability to handle fresh-air and ventilation loads as prescribed by ASHRAE 62.1/62.2. This can be achieved by introducing a separate system called DOAS (Dedicated Outside Air System) as mentioned above. This usually requires ducts to circulate the fresh air.
3. **Proprietary Systems:**
   Components are not compatible across manufacturers, and there is no secondary market for components. Building owners are a captive customer once the system is installed, exposing them to a lack of price competition for replacement parts and future building retrofit projects. Manufacturers are often involved in the design of VRF systems. Structuring bid documents for open bidding of VRF systems is difficult because of manufacturer involvement in the final design. (Thornton & Wagner, GSA, 2012)
4. **Higher equipment costs:**
   VRF Systems have traditionally been considered as more expensive than chilled water systems. Jeff Ledsinger of Bartos Industries in Houston, Texas shared his thoughts about this notion in an interview with ACHR News in November 2014 issue: “When VRF is compared to other technologies on an equipment basis, just equipment versus equipment, it’s usually going to come in higher because there are more components and they are a little bit more advanced electronically,” Ledsinger continued. “But, then you start factoring in labor savings, the savings on controls, and other savings. All of that adds up to a lower upfront cost than most competitive technologies.

The United States Market

VRF Systems entered the U.S. market in early 2000s beginning with Mitsubishi Electric in 2003 followed by others. Daikin introduced VRV units in 2005 with products imported from Japan and Europe (Today's AC and Refrigeration news, 2017). Even though, the pioneers of air-conditioning, Carrier formed a joint venture with Toshiba in 1999, they introduced the VRF systems in North America only in the year 2012. (Carrier VRF 2016). Fujitsu General started offering their VRF products in North America in 2011. Another significant event in the U.S. VRF market would be players like Johnson Controls and Hitachi joining hands in October 2015. Johnson Controls has huge market share in the U.S. which, when coupled with Hitachi’s state-of-the-art VRF technology, can be a game changer.

Key Players in the U.S. VRF Market:
The VRF Systems market in the U.S. have traditionally been dominated by Japanese manufacturers. However, in last 5 to 7 years, some new manufacturers have set up their shops here. The list below provides a snap-shot of VRF system manufacturers / suppliers in the U.S.

- Toshiba-Carrier VRF Systems (United Technologies)
- Fujitsu General
- Trane by Ingersoll-Rand
- Panasonic Corporation
- Mitsubishi Electric
- Daikin North America
- Johnson Controls – Hitachi VRF
- LG Electronics
- Samsung
- Lennox Commercial

Most of the above-mentioned manufacturers / suppliers have their manufacturing facilities in China, Japan and other parts of South-East Asia. However, Daikin, after acquiring Goodman, has recently started manufacturing their VRV^{TM} equipment in a large facility in Houston, Texas.

Research Methodology

Further to our understanding of the VRF systems along with their advantages and the U.S. market conditions, this research required more detailed analysis of factors contributing or affecting the growth of this technology in this region. During last 5 years (2011 to 2016), some independent analysts have tried to carry out surveys and investigations and have published their findings. Literature about these findings was obtained and reviewed as a part of this research. As a part of this literature,

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extracts from several engineering news articles focusing on VRF technology, in which, several key people from leading VRF manufacturers were interviewed, were also reviewed (Appendix-1). One of the goals of this research was to consolidate this information, analyze and present it in a more logical manner with focus on a specific region. However, findings from these reviews needed to be re-substantiated, especially when the focus is on a specific region. One of the best ways of collecting first-hand information was to reach out to the leading engineers and contractors who design and install HVAC systems in this region. This was achieved by conducting a survey in which engineers and contractors active in the South-Eastern United States provided their responses (Appendix-2). The questionnaire of this survey was carefully drafted to understand and analyze the following…

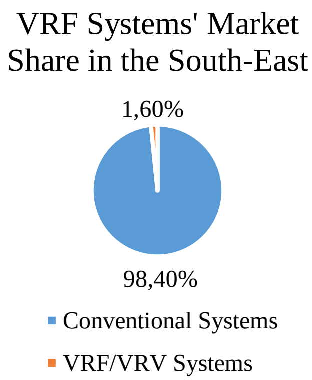
- What is the extent of penetration of VRF technology?
- What is the level of awareness about this technology?
- What types of projects are being preferred for VRF systems?

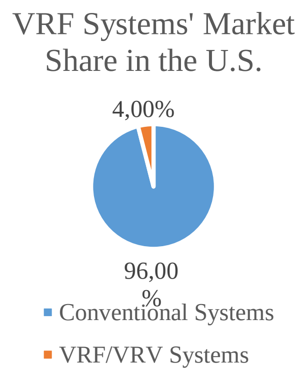
Data Analysis

The questionnaire was targeted towards HVAC industry professionals, more specifically the designers/ engineers and contractors. Some of the responses received were from the leading A/E firms practicing in the South-East. Few responses from the U.S. Army Corps of Engineers (USACE) were quite interesting and their policies regarding the use of VRF System were understood. As the questionnaire was prepared in 2 parts, the analysis presented below is in 2 sections.

Geography and Volume of Projects:

- Respondents to the survey have been practicing in almost all South-Eastern states but more notably in Florida, Georgia and Tennessee.
- Almost all respondents' organizations are practicing for more than 25 years in the HVAC industry.
- Number of commercial projects (combined) completed by the respondents in last 5 years is **6700**.
- Out of these, only on **109** projects the VRF Systems were installed. This corresponds to only **1.6%** of the total volume.
- Average tonnage value for these projects was found to be about 50 tons.





Level of awareness about VRF Technology:

- Respondents stated two main reasons due to which a VRF system can be proposed on a project…
  1. Energy efficiency – 30% to 40% lower energy costs.
  2. Space saving advantages – Ductless and machine room less system

- On the other hand, many different reasons were given by the respondents for not choosing this system over a traditional chilled water based systems. More notably the following…
  1. Complexity of the system
  2. Unavailability of trained installers and service technicians
  3. Compliance with ASHRAE standards for fresh air and refrigerant concentration

- Most of the respondents are familiar with only 1 or 2 manufacturers which provide a solution for extreme cold weather conditions.

- Out of various categories of projects, the most popular choices to propose a VRF systems were…
  1. Light commercial projects
  2. Refurbishment or retro-fit projects
  3. Multi-family residential projects

- For commercial projects, multi-tenanted small office projects were chosen as more suitable for VRF systems.

- Out of 10-11 leading VRF brands, Toshiba, Mitsubishi, and Daikin were found to be the most popular choices.

Responses from the U.S. Army Corps of Engineers specifically pointed towards the current policies they have adopted. According to the directives received in March 2017, the Air-Force has stopped permitting VRF systems on their projects. The Army, though allowing the use, has strongly discouraged VRF Systems. On the other hand, the Navy has posed no restrictions but has asked for compliance with ASHRAE 15 safety standards for refrigeration systems. In addition to this, the USACE has also pointed out that using proprietary systems is not permitted. Most VRF manufacturers have closed proprietary control systems. The Unified Facilities Criteria (UFC) requires an open protocol system. It states that “An Open DDC system is characterized by the ability for any qualified entity to readily modify, operate, upgrade, and perform retrofits on the DDC system.” (USACE, Mar 17)

Conclusion

The results of this research study have been quite convincing. Let us conclude this research by answering 3 main questions of this research paper.

1. What is the condition of commercial VRF market in the South-Eastern United States?
2. Why have the VRF Systems not been popular in the U.S.?
3. What is the future path for this technology in the U.S.?

At the outset, let us agree that the results of this research clearly state that VRF Systems have not been popular in this part of the world. As mentioned earlier, the market share of VRF systems in the U.S., as a whole, have only been 4%. In the South-East, this was found to be even lower at merely 1.6%.

After analyzing the responses on section-B of the survey questionnaire, we can conclude that there’s sufficient awareness about the advantages of VRF technology among leading HVAC engineers. However, they are not preferring this system due to issues related to availability of trained technicians, complexity of the system, in addition to compliance to standards. Moreover, the USACE, other than compliance, is also concerned about the VRF systems being proprietary. This means, having different control protocols for different buildings for the same client is a challenge that VRF manufacturers need to tackle.

Respondents’ choice of projects on which VRF could be the ideal solution were light commercial (multi-tenant offices), multi-family residential and retro-fit projects. The first two choices state that modularity and flexibility of design are important factors. Retro-fit projects, obviously, are chosen to get VRF Systems due to space-saving and duct-less solutions they offer.

Several factors need to be considered to conclude on why the VRF systems have not been popular in the South-East. My conclusion below, is not limited only to the analysis of data received from the survey. Careful consideration has also been given to what VRF industry leaders have to say about the American HVAC market as well as other literature reviewed, as mentioned above. Hence, following can be concluded as reasons for a very limited growth of this technology in the South-East.

Geography and Climate:
The U.S. has been geographically divided in various regions viz. North, North-East, West, Mid-West, South-East etc. Out of these, the North, North-East and the West regions have seen higher commercial growth. Out of these three regions, the North-East has seen rapid growth during the second industrial revolution. Development in the West and the South is comparatively recent. We can, hence, infer that while majority of South-East was being developed, the conventional chilled water systems were the best solution. The structures were planned for this and till date most of them function quite well. This, along with North-East predominantly falling under colder climatic regions, have been very important factors to consider. VRF systems have, traditionally, not been considered suitable for colder climates.
Another important geographical factor to consider is that the U.S. is located quite far away from the manufacturing facilities of leading VRF providers. Except for a very recent development by Daikin to manufacture VRF machines in their Texas plant, all other providers manufacture their machines in Asia. This causes longer delivery times and most commercial projects have very limited construction timelines. On the other hand, most chillers and AHUs are manufactured locally.

Timing:
As stated above, VRF systems entered the U.S. market in the new millennium. By the time this technology started picking up some market share, the recession took over. This, arguably, has impacted VRF's growth, to a great extent, more specifically due to higher initial costs. Even after 2010, the technology didn't quite get the luxury of asking for a premium Cap-Ex, especially in a more conservative economic growth. Since 2010, VRF has seen considerable amount of growth in the West and the North-East. However, the South-East, with an exception of cities like Atlanta, GA, Nashville, TN and Raleigh-Durham, NC, has not been growing so rapidly. Moreover, by the time VRF systems entered the market, most of the commercial developments were planned for conventional ducted air-flow systems. These buildings have not yet reached a stage for refurbishment.

Economics:
One of the major factors to limit the growth of VRF in the South-East is economics. This can be concluded with two main points, Energy-Economics and Space-Economics. Energy prices have historically been lower than the national average in this region. Due to this, energy efficiency aspect of VRF systems has not been quite convincing for new projects. Easy availability of water for cooling needs would also be a factor worth mentioning. In addition to the energy factor, space availability of commercial projects in the South-East has been much more than other crowded cities in the North-East and the West. Hence, the space saving advantage of VRF systems has not yet been a decision maker. This, of course, is changing in the bigger cities like Atlanta. The economic conditions in the West and North-East are quite the opposite. Energy rates are higher, space is at a premium and hence, VRF systems are seeing better prospects in these regions.

Standards and Regulations:
Standards and regulations for HVAC industry are primarily governed by ASHRAE, AHRI and U.S. Department of Energy. Out of several standards and regulations, the ones that have impacted the growth of VRF's market share are…

- ASHRAE Standard 15 which regulates refrigerant safety and environmental impacts and
- ASHRAE Standard 62 for Ventilation and Indoor Air Quality which states the requirement of outside air (fresh air)

Both, the survey respondents as well as USACE have raised concerns about VRF systems' compliance to these standards. This clearly indicates that the VRF industry needs to work on solutions to overcome this issue. On the bright side, VRF systems have shown excellent results against ASHRAE's standards for minimum efficiency ratios including full-load energy-efficiency ratio (EER) values, and part load, integrated energy-efficiency ratio (IEER) values. (Thornton & Wagner, GSA, 2012)

Finally, we need to figure out what the future holds for this technology in the U.S. Industry leaders in VRF market are very optimistic about its future. Independent market research reports also point towards a bright future for VRF systems in the U.S. According to the analysts at Markets&Markets, the VRF systems market in North America was valued at US$ 1.27 billion in 2015 and it is expected to reach US$ 3.16 Billion by 2022 at a CAGR of 13.5%. This, of course, is dependent on the commercial construction activity which is increasing since last few years. (Markets&Markets, 2016).

As the utility prices keep increasing, more and more requirements for lowering operating costs will call for choosing VRF systems over conventional chilled water systems. This has been evident in growth of VRF sales in North-East and western states like California, Arizona, New Mexico etc. where utility prices are above normal. Another important factor for growth in VRF systems sale in the North-East is that many office and government buildings are now 60-80 years old and don't have duct-work. In the South-East, however, VRF manufacturers need to work on various challenges stated above, in order to increase VRF's market share.

To summarize, VRF systems have not been popular in the South-Eastern United States. Main challenges the VRF manufacturers need to address are including but not limited to the following…

- Increase trained installers and technicians base
- Spread awareness about energy savings
- Provide better solutions for ASHRAE compliance
- Decrease equipment lead times
- Develop and offer open protocol solutions

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A model to approach BIM adoption process and possible BIM implementation failures.

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Abstract

Adoption of Building Information Modelling (BIM) has increased significantly over the last few years. In France, the level of BIM adoption is measured as quite low compared to other countries. Many guides, protocols and mandates have been produced by governmental bodies and industry associations around the world to facilitate BIM adoption but it mainly focus on technical requirements or describe good practices. This paper is part of a research project that aims to facilitate BIM implementation for design firms by providing an implementation guide or method. This method would be organization-centered (based on the specificities of the company) with more organizational and managerial than technical considerations. Connecting BIM Adoption-Implementation literature with change management (a domain that provides models and strategies to analyze and conduct change) carries an interesting research potential that is insufficiently investigated. The objective of this article is to have a relatively comprehensive view of the factors that can influence the success or failure of BIM adoption, especially at the implementation phase.

Keywords: BIM; AEC; AECO; architecture firms; adoption; diffusion; implementation; implementation failure; adoption drivers; implementation drivers; adoption decision factors; adoption failure; implementation failure; change management; change; risk management; literature review; conceptual model; guide; method.

1. Introduction

Building Information Model/Modeling/Management (BIM) is a technology (including technique and processes) based on exploitation/exchange of digital mock-up between construction project actors for buildings lifecycle management. It is considered as an emerging technological shift [1] within the Architecture, Engineering and Construction and Operation (AECO) industry.

Many guides, protocols and mandates have been produced by governmental bodies and industry associations to facilitate BIM adoption [2] but it mainly focus on technical requirements or describe good practices. Connecting BIM diffusion/adoption/implementation literature with change management (a domain that provides models and strategies to analyze and conduct change) carries an interesting research potential that is insufficiently investigated [3].

This paper is part of a research project that aims to facilitate BIM implementation for design firms by providing an *implementation guide or method* based on the specificities of the company, with more organizational and managerial than technical considerations. The first step is to study how this company works to identify organizational factors that are likely to affect implementation (cause implementation to fail or succeed). It comes down to identify risk factors (internal context, external context, culture, interactions, systems and people [4]) which may make BIM implementation more complex, and manage it (as in risk management field, for transition project [5]).

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The objective of this article is to have a relatively comprehensive view of the factors that can influence the success or failure of BIM adoption identified in the literature, especially at the implementation stage. First, we clarify definitions of diffusion, adoption and implementation (part 2). Then, we will identify the factors that have been identified in the literature as playing a role in the adoption and success or failure in implementation of an innovation (part 3). In the discussion (part 4) we will propose *a model to approach BIM adoption process and possible BIM implementation failures* based on the state of the art proposed in part 3. As a conclusion (part 5), we will present research perspectives based on this model.

2. Diffusion, Adoption, Implementation.

BIM is considered an innovation. The lexical field generally attributed to the spread of innovations is also attributed to BIM (diffusion, adoption and implementation). However, the definitions of these terms are not always explicit in BIM-specific literature, and are sometimes different:

- **Diffusion** is "a concept that represents the spreads of the system/process within a population of adopters" [6]. "The diffusion process is characterized by increases over time in both the number of firms using or owning a technology (inter-firm diffusion) and more intensive use of the technology by the firm (intra-firm diffusion)." [7].
- **Implementation** is "a set of activities undertaken to prepare for, deploy or improve specific deliverables and their related workflows" [6].
- **Adoption** is the most unclear term. It sometimes refers to a company's management *decision* to start integrating a technology; to the *moment* the technology is well mastered; or to a *process* that includes implementation.
  Everett Rogers published in 1963 the first version of one of the most famous research on innovation: *Diffusion of Innovations* [8]. He describes the innovation-decision process in five stages (table 1). This model has been adapted, renamed, and became the model of the adoption process [9] (see table 1) and readapted more recently in BIM-specific literature [10] (table 1), where Decision (at stage 3) became Point of Adoption.

Table 1 : Different models in five stages that describe innovation –decision process / adoption process.

Stage 1	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**	**Ref.**
Knowledge	Persuasion	Decision	Implementation	Confirmation	[8]
Awareness	Interest	Trial	Evaluation	***Adoption***	[9]
Awareness	Intention and interest	Point of ***Adoption***	Implementation	Confirmation	[10]

But considering adoption as a decision is not new: "innovation implementation presupposes innovation adoption, that is, a decision, typically made by senior organizational managers, that the employees within the organization will use the innovation in their work" [11]. This definition is also used in Information Technology Adoption literature for Technology Acceptance Models (TAM) : "TAM2 reflects the impacts of (…) forces impinging on an individual facing the opportunity to *adopt* or *reject* a new system" [12]. This is in continuity with Roger's model in which stage 3 can lead to adoption or rejection, and Stage 5 is the continued (or effective) adoption or rejection.

In BIM-specific literature, Succar and Kassem [13] describe BIM adoption as "a single construct combining the concepts of implementation and diffusion".

Given that we focus on the process through which companies go through to be able to use BIM, we must make a clear distinction between the **decision to adopt** (which we will call Decision of Adoption or **DoA**), when Implementation is effective (EI effective implementation), and the moment **Technology has been effectively adopted** (Confirmation of Adoption or CoA) (fig. 2 presented in part 4).

3. BIM adoption influencing factors

Innovation adoption is a long and complex process, of which implementation is a part. It is necessary to differentiate what influences decision to adopt BIM and what impacts the success of implementation.

3.1. Risk Management

BIM literature has focused much on the level of adoption (especially comparative analysis) and benefits associated with implementation [5, 6, 14–16]. But any operation that generates *benefits* is also likely to produce *negative effects* [17]. Digital transition and change in a company is a risky operation.

Risk event is “what might happened to the detriment or in favor of the project” [17]. All risk events do not have the same chance to occur, this is called *uncertainty of the even* [17]. Risk management consists in identifying risks, analyzing them and formulate a response to anticipate their occurrence [5, 17, 18]. It is therefore interesting to consider risk management in BIM implementation methods.

Some research focus on risks on BIM *projects* [18], we focus on risks for *firms***.** We aim to identify *recurring risks* (organization death, returning back to previous practices, and so on.) and *risk factors* (what increases the likelihood that the risk occurs) related to digital transition in design firms.

Bonanomi [5] identified two types of risk factors for implementation : endogenous (coming from internal context of the firm) and exogenous (coming from external context of the firm) risks. Social, managerial, technical, economical and institutional risks linked to BIM implementation in design firms are identified in the literature [5, 18]. We propose to link these risk factors with generic literature on innovation adoption and change management in order to clearly differentiate **adoption decision factors** and **implementation factors**.

3.2. Innovation adoption factors

Research on the factors that influence decision to adopt is numerous, and arise from various fields.

Sociological psychology has been investigated to understand psychological, social aspects involved in decision of adoption of an innovation: these models and theories mainly focus on the perception a *user* has on the technology that determine the ease of use and usefulness of this technology. This perception is itself partially determined by the user profile and characteristics. The best known of these theories one is Technology Acceptance Model (TAM), proposed by Davis [19] and updated with Venkatesh [12]. A representative state of the art of these models can be found in Tetard and Collan’s work [20].

Economy, sociology and *strategic management* have been investigated through Institutional Theory (INT) [21], which describes the institutional pressures that motivate *organizations* to perform change : coercive (responding to cultural expectations), mimetic (facing uncertainty), normative (undergoing standardization of training and procedures).

A summary of factors that affect innovation adoption coming from various literature can be found in [22] (innovation-specific), cited by [10] (BIM-specific) :

- **Perceived BIM/innovation characteristics**:
  Firm’s idea about value of the innovation [22] as perceived usefulness of a technology and perceived ease of use [19], relative advantage, compatibility, complexity, triability, observability, and technological factors [8].
- **Adopter characteristics**: (this factor does appears in [22], and is integrated to “internal environment” in [10]) Company’s general attitude towards the type of innovation, and financial resources it devotes to IT technologies.
- **Internal environment characteristics:**
  Top management support, communication behavior, financial resources, organizational readiness, social motivations, organization culture, willingness/intention, organization size.
- **External environment characteristics:**
  Coercive pressures, mimetic pressures, normative pressures, market forces and supply chain integration

This literature is very useful to understand what can make an enterprise or an individual choose to adopt a technology. Factors that *facilitate* decision of adoption are called adoption decision *drivers*. But the factors here identified intervene *before* the decision to adopt (at stage 3 in Roger’s model). So it doesn’t help understanding what sometimes lead adoption to fail after decision of adoption has been taken.

3.3. Are there companies unable to integrate an innovation/BIM?

As we try to construct a method to facilitate digital transition in design firms, it is legitimate to ask whether certain companies could be unable to integrate BIM.

A large part of organizational, management and sociological literature subscribes to ***adaptation perspective*** [23]. In this perspective, leaders or top managers scan the environment of the organization to detect opportunities and threats and formulate strategic responses to adjust organizational structure appropriately. Changes are therefore made to lower organizational death rates of organizations.

The adaptation perspective has been challenged in 70's with ***population ecology theory*** [23–25] which argues that organizational have high levels of structural inertia which make organizational adaption difficult, and sometimes impossible. One of the major arguments of *population ecology theory* is that organizations rarely make major adaptive changes (organizational changes are considered more often *disruptive* – as does BIM) and that there are number of obvious limitations on the ability of organizations to adapt [24]. Two types of limitations are mentioned:

- **Inertial pressure** are the pressures that come from the company itself as **1**- choices made previously (equipment and specialized personnel), **2**- the kind of information decision makers receive, **3**- internal political constraints, and **4**- the history of the firm [24]. This implies that not all companies are equal in the face of change.
- **External pressures** are **5**-legal and fiscal barriers, **6**-information dissemination channels, **7**-legitimacy constraints and **8**-collective rationality problem [24].

Not all companies are equal in facing change, which is interesting in the perspective of massive BIM adoption, how BIM can be implemented, and consequences it can have on the AECO industry.

In Rogers' [8] and Ahmed's [10] models, only the rejection decision can stop the adoption process (at stage 3, see table 1). Hannan and Freeman describe pressures (internal / external) that can lead to implementation or reorganization fail, the different steps where implementation can stop and what form this failure can take (see fig. 1): an organization may die because it has not adapted quickly enough (d). If a structure decides to reorganize (a), the operation can lead to success (c), to death (e) or to a return to previous practices (b). It is also possible that the new configuration is not adapted to environment, and then the organization can die (f).

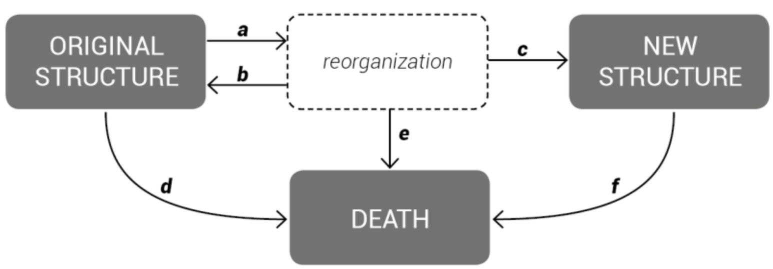

Figure 1 : State space for the Process of Fundamental Change in Organizational structure, adapted from [26].

In the *population ecology theory*, the term "population" refers to aggregates of organizations rather than member [24] : adaptation of organizational structure to environments occurs principally at the population level [26]. In view of that, organizations that fit the environment survive, and those who are not able to adapt quick enough die.

The way in which the identified factors influence firms' mortality has been the subject of hypotheses (called assumptions in [26]). They concern ***characteristics of the company*** (size, age specialized or generalist), ***external environment*** (stable, uncertain) and the ***implementation method for change*** (type, speed) [24]. Some of these hypotheses have been tested and empiric study of these factors do not show clear impact of these characteristics on mortality of an organization and have not shown predictive capacity of this theory [23]. These factors remain however interesting because they have not been investigated in the case of BIM adoption and implementation, and studying organizations as populations can help to identify general trends in BIM field.

3.4. Change management

In the 80s and 90s, ***software development paradigm*** (when each company develops its own tools, adapted to its practice) gave way to ***software edition paradigm*** (publishers market software on a large scale for the greatest number). This changeover is at the origin of the very pragmatic managerial questions linked to the support of companies in the integration of information technologies [27]. Change management is a domain that provides theoretical/practical models and strategies to analyze and conduct change [3]. This discipline is focused on the implementation part of adoption, and can be really interesting to investigate BIM implementation.

On the basis of a change management state of the art [27], we summarized elements that are identified in this literature as factors that impact implementation. They are classified into two categories:
① the ***characteristics of the company context*** (table 2) and ② ***change characteristics*** (table 3).

Table 2. ***Characteristic aspects of a company*** ① at 3 different levels: the global level (L3), the organization level (L2) and the personal level (L1).

Level	Context	Description	References
L3	**External context**	Social, economic, competitive, and political environment.	[28], [4]
L2	**Culture**	Vision, principles, beliefs, values, projects (products), strategies	[29], [30], [28], [31], [4]
	Interactions	Hierarchy, division of power, distribution of work and responsibilities, collaboration.	[29], [30], [28], [31], [4]
	Systems	Software, hardware, processes	[29], [31], [4]
L1	**People**	People, experience, seniority, career stage, skills.	[29], [31]

Table 3. ***Change characteristics*** ② that have been identified in the literature as playing a role in the success of the change (adapted from [27])

Caract.	Dimension	Description
Extent	**Global**	Change affects all activities and units of the organization. The company's strategy and culture evolve [27].
	Partial	Change affects a portion of the organization, preserving the previous strategy, culture and structure. It is most often insufficient to modify the company's performance [27].
Depth	**Disruptive**	A disruptive change marks a big difference with past, with a clear discontinuity. It changes strategy, process and organizational culture and affects the company's performance [26] [27].
	Adaptive	An adaptive change is a modification of the actual situation. It makes evolve lightly content, process and missions of the organization [26] [27].
Rhythm	**Fast**	A fast change is a redress and a resolution against a past situation, but too rapid a change can put the organization at risk [32].
	Slow	It consists of a gradual approach to ensure a new balance thereafter. Too slow a change can lead to getting used to an undesirable situation [32].
Base	**Imposed**	Imposed change is a change for which management acts decisively and where there is little opportunity for negotiation [27].
	Negotiated	Managers are caught between limiting resistance to change and respond to customer demands. Convinced that imposed change has little chance of success, they integrate teams to limit resistance. It is difficult to place the cursor between firmness and negotiation [27].

Elements in Table 2 are very similar to those found in the population ecology theory (inertial and external pressures). Factors summarized in table 3 have been the subject of empirical studies and action research: their involvement in success/failure of implementation have been demonstrated, but AEC-specific examples are rare. Lines [33] tried to determine what causes more resistance to change in the case of implementation of new processes in AEC firms (resistance to change can lead to adoption failure). He proposed hypothesis based on the ***organization characteristics*** (Project: scope, size, duration; People: position level, career stage) and ***change characteristics*** (Organizational expectations: implementation speed, organizational shift; implementation approach: change message received, presence of formal agents, involvement of change agent). He demonstrated that all these hypothesis, except « expected organization shift » are strongly correlated with resistance to change. BIM-specific studies of this type are extremely rare, and some of these factors are quite difficult to measure or to identify in firms.

4. Discussion

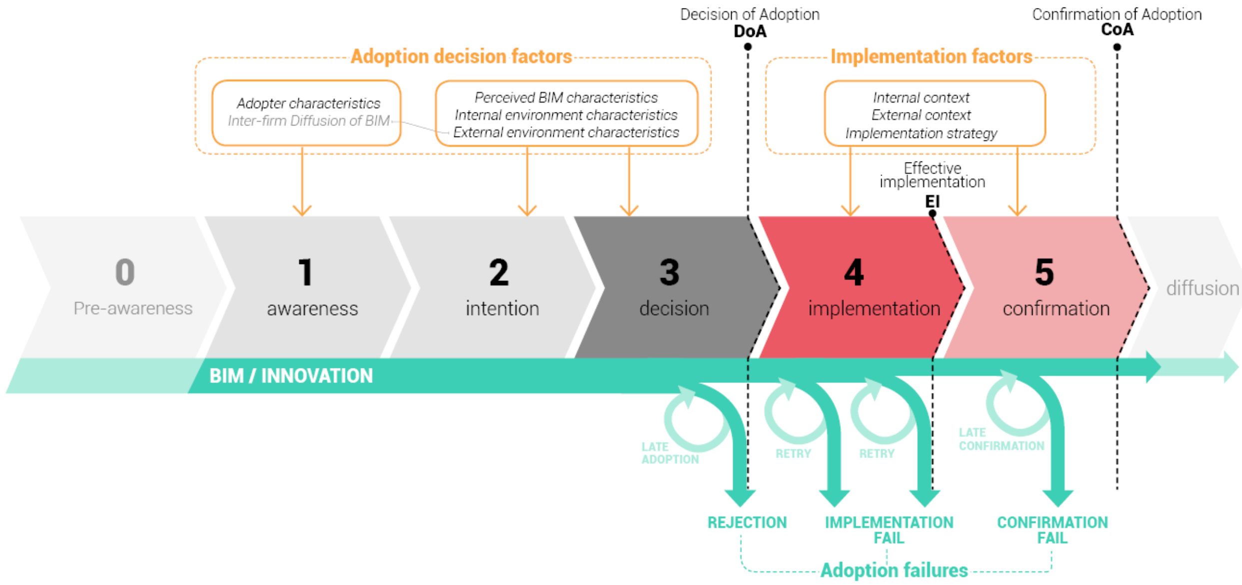

Figure 2 : Model of the BIM Adoption process, with possible adoption failures; adapted from [8, 10]
This figure is an evolution of the "conceptual model for investigating BIM adoption decisions" [10]. We do not use the term "conceptual model" to avoid confusion with "conceptual models" used in Information Systems to designate a representation of a system.

Innovation diffusion models and technology acceptance models have been progressively appropriated in BIM-specific literature. However, diffusion, adoption and implementation processes are insufficiently defined and described. Based on Roger's model [8, 10], we consider that BIM Adoption is a process (fig. 2), which begins with the **awareness** of the existence of this innovation (stage 1), followed-up by the eventuality of the **intention** (stage 2) and **decision** to adopt (stage 3). The **Decision of Adoption** (**DoA**) is an important moment, when the company's management begins to bring about c hange in the company; it also marks the beginning of the implementation process.

In the study of BIM adoption, the focus is often made on **adoption decision factors** (factors that influence decision of adoption). They can be summarized in four categories: **perceived BIM characteristics**, **adopter characteristics**, **internal environment characteristics** and **external environment characteristics** (including inter-firm diffusion of innovation).

Decision of a company's top management that the people in the firm will use BIM is not sufficient to make an organization adopt it or to explain the rate of BIM adoption in AEC industry. Some elements involved in the adoption process are beyond the control of the decision-making group and may cause the adoption to success or to fail, after the DoA. **Implementation factors** affect implementation (stage 4), under or beyond the control of the decision-making group.

Implementation factors have been explored in different fields and models, presented in this article. They can be classified into three categories, that do not carry the same name in the various literatures, but refer to the same concepts: **internal context**, **external context** and **implementation strategy** (table 4).

Table 4. **implementation factors** categories names in various literatures

	Internal context	*External context*	*Implementation strategy*
Population ecology theory	Inertial pressure	External pressure	Nature or reorganization
Risk management	Endogenous risk	Exogenous risk	Endogenous risk
Change management	Characteristic aspects of a company (L1 & L2 in table 2) *culture, interactions, systems, people.*	Characteristic aspects of a company (L3 in table 2) *external context*	Change characteristics (table 3)

The adoption process can be interrupted (**Adoption failures**) after **stage 3** at different steps:

- **Stage 4**: Adoption can fail at the beginning of implementation, for example if resistance to change is very strong in the company; it can also fail during implementation, if the company is not fast enough to operate change, if the company returns to previous practices or dies because of disruption created by change (fig 2).
- **Stage 5**: Adoption can fail after implementation, during the confirmation stage (fig 2), for example if the if the implemented technology is not effective in practice for the organization and is abandoned, or if the company dies or goes back to previous practices.

We have shown that the innovation adoption process can fail at many stages. **Implementation factors** are little-known in the case of BIM, although recent research has taken a more in-depth look at this topic [34, 35]. We don't know yet what influences the more BIM adoption, despite the numerous surveys conducted on BIM topic [14, 36–39]. Some of the factors identified in this article can help understand what can lead implementation or adoption to fail. However, there is currently a lack of quantitative studies that focus on implementation factors. Of course, it would be difficult to set up an experimental protocol allowing a factor to be isolated in order to study its impacts.

5. Conclusion

Motivation to adopt an innovation changes with the number of other firms in industry that already successfully implemented this innovation. At the beginning of the inter-firm diffusion process, adopters are more focused on strategic importance of the innovation for the organization, and external forces like the parent company, industry competitiveness. Later, they tend to be focusing more around practical implementation issues and budget [22]. Given the increasing level of adoption of BIM and incentives for adoption provided by governments, it is important to focus now on very practical issues on the firm's implementation. Large-scale surveys that assess the level of BIM adoption are numerous, but seem to not focus on characteristics of the firms, and how they drive change.

It is important to note that the way change is taking place is little known while the stakes of massive BIM adoption are high. The review presented in this paper can be completed with the diffusion of a large-scale survey to architecture firms in order to fix the lack of information available on implementation factors in design firms. This research will be used to develop a method to support the implementation and digital transition of architecture firms in France.

This review also opens up other perspectives: it can be used to study the impact of massive BIM adoption in AECO industry, considering some companies may be unable to integrate these technologies. It is conceivable that the market will be restructured in a rather profound way, especially in France, where most of the companies are very small and still work in a very artisanal way.

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A Study on Adjustment Method of Finishing Work Schedule based on Image Detection for High-Rise Building Construction

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Abstract

As recent buildings have been getting higher and larger, the finishing work management has become a key factor for successful projects. Although many finishing work management techniques have been trying to set up a measureable scheduling plan at early stages before construction lift installation, but schedule adjustments according to site condition and construction progress are inevitable because there are many unexpected variables. To develop the assistance tool for finishing work management techniques such as TACT or LOB(Line of balance), in this study, we suggested image-detection(helmet detection) based labor counting method. The internet protocol cameras at each inside of construction lift cages collect and send photography data to processing server. And through image detection processing using photography data, it is possible to count the number of workers put into each finishing work. The worker count result is used for comparison with the existing finishing work schedule. This study has served as a key lead of lift monitoring based construction process management. Therefore, it is anticipated to settle as a system based data-centric construction management technique in the field.

Keywords: Constucruction Lift, Finishing work schedule, Image Detection, Helmet detection

1. Introduction

Over the past few years, the number of high-rise buildings constructed in Korea has significantly increased. In case of Korea, there are many buildings over 500m high, which completed in 2017. Despite the development of high-rise construction, there are still many problems on process management. Especially, there are many needs of finishing work improvement caused by mix of work activities at the same time and the rise of vertical movement distance.

Finishing work takes part of approximately 15~20% of total construction cost. As buildings get higher, the most critical problem of finishing work phase is lifting management regarding manpower and materials [1]. The main reasons for lifting management problems are caused by long distance vertical transportation and increase of materials on finishing work. In case of high-rise building over 500m, in the Republic of Korea, an additional cost of over $ 20 million is generated because of finishing work delays over 3 months. Such kinds of additional cost, incurred frequently, show the problem of current lifting plan which is used in most of high-rise construction projects.

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The existing method on finishing work schedule management, including lifting plan for each construction phase and peak-time period, is based on labor productivity (Man·Day/㎡) which has been generally used in buildings under 300m high. Therefore, another access to correct errors of existing lift management is requested for high-rise building construction.

2. Finishing work schedule management for high-rise construction

Although there are differences in each company and in each region, the TACT technique is most commonly used for finishing work management for high-rise building construction [2]. The TACT technique is a finishing work process management method for sub-dividing work into each floor and process, distributing human resources and equipment into even periods of each construction time, adjusting the preceding and lagging relationship of works on the same floor, and planning for the sequential operation of the work on each floor. Even though we are not able to establish whether every vertical plan is based on the TACT technique, there is no theoretical difference between the as-is vertical plan and TACT.

Finishing Work Activity	Man·Day/㎡	㎡/Man·Day
Activity 1	X1	1/X1
Activity 2	X2	1/X2
Activity 3	X3	1/X3
Activity 4	X4	1/X4
⋮	⋮	⋮

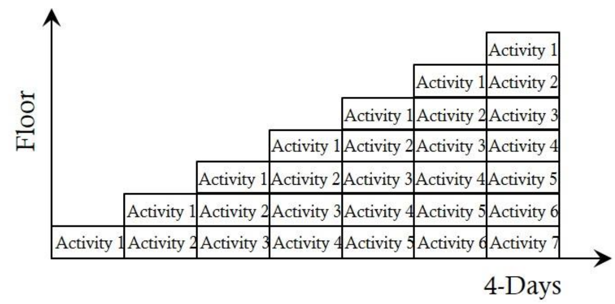

Fig. 1. TACT based Work Activity Arrangement

TACT is performed using the process schedule, assuming that all the TACT-elements are implemented in the same manner within the consistent cycle. However, the degree of progress in TACT process plans is subject to be changed depending on the work situations in the field. In addition, TACT makes it feasible to find delay factors and modify TACT on the plan, using analytic data of the operation and change plan to suit the current situation.

The number of mobile workers on each floor is a very important measure as a basis for judging the progress of the current finishing work. The field manager can check the progress of each finishing activity by monitoring the number of workers on a daily basis from 7:00 to 8:00 (the usual time the worker is assigned to each floor).

3. Unmanned Construction Lift & Sensor based Monitoring

In addition to counting the number of workers, various lift sensors are essential to monitor lift conditions for finishing work. Especially, ‘position’, ‘moving direction’, ‘call floor’ and ‘target floor’ are important factors in recognizing the worker’s assigned target. The sensor module consist of Double Senor type Encoder, Limit Switch, Separating type Current Transformer, Proximity Sensor, Load Cell. The processing board of sensor data at inside of construction lift cage and encoder sensor are as shown in Figure 2 and Figure 3.

This study has expended the sensor-based monitoring from the lift operation with a driver, to the unmanned operation system. The main difference of sensor monitoring between existing manual operation system and unmanned system is the target floor input board. Because the unmanned system does not have a driver, the workers have to appoint a lift moving target themselves. By worker’s choice, lift-car’s estimated moving distance and time are calculated according to height of floor which pre-set in operation processing board and cycle-time equation as shown in (1).

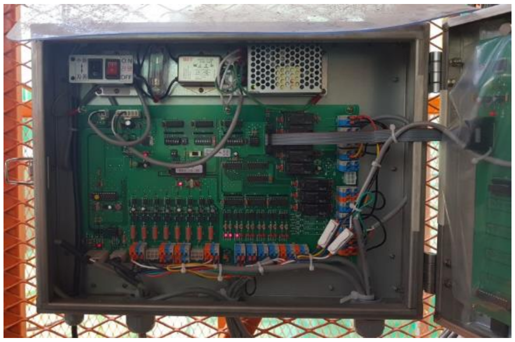

Fig. 4. Data Processing board

Fig. 5. Encoder Sensor

$$\text{Unit Cycles} = t_0 + (s_r \times t_1) + 2\{((s_r + 1) \times t_a) + \{(h_r - h_{r-1}) - ((s_r + 1) \times d_a)\}/v\} \quad (1)$$

The unit-cycle time equation includes loading time(t_0), unloading time(t_1), number of stops(s_r), height of stop floor(h_r), accelerating/decelerating time(t_a,d_a) and maximum lift speed(v). Eq. (1) can be used to determine the number of workers for each floor by matching movement history data from encoder and Image detection data. The unmanned lift system supports to make data matching faster. Figure 4 and 5 shows the components of the unmanned construction lift system including calling device and target floor input board.

Fig. 4. Calling Device

Fig. 5. Target floor input board

4. How to count man power

- It is necessary to look at various image-detection and deep-learning technologies as open source considering the environment inside the construction lift-car, where frequent visibility redundancy occurs. Deep-learning based computer vision is the core technology to record object state changes inside the lift-car.

4.1. Selection of image detection method

To figure out most suitable object detection method, we conducted comparative reviews in terms of performance and objectives of various commercial products and research. The comparison of each image-detection is as shown in Table 1.

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Table 1. An example of object detection methods.

Examples	Characteristics
R-CNN	Testing time per image 50 seconds. The mean average precision (mAP) for each query is of 66% on VOC 2007 test-dev. [5]
Fast R-CNN	It builds on previous work to efficiently classify object proposals using deep convolutional networks. Achieves near real-time rates using very deep networks, at 2s per image. Multi-scale design based on anchors, computed on a single-scale image. [7]
Faster R-CNN	It is a single, unified network for object detection. It does not need external region proposal. The test-time speed of obtaining results is of 200ms per image. [5]
You Only Look Once (YOLO)	It processes images in real-time at 45 frames per second. On a Pascal Titan X it processes images at 40-90 FPS. .
Single Shot Detectors (SSDs)	The SSD approach is based on a feed-forward convolutional network that produces a fixed-size collection of bounding boxes and scores for the presence of object class instances in those boxes, followed by a non-maximum suppression step to produce the final detections. [6]

Object detection methods perform different from one another, as shown in **Table 1**. This section describes the different accuracy on real-time detection, the approach applied to stage detectors bounding boxes and applying high-quality classifiers. R-CNN applies the CNN feature extraction to possible objects and then finally classifies the regions. In comparison, Fast R-CNN used a single network to compute image features (CNN), classify (SVM), and tighten bounding boxes (regressor) [7]. Subsequently, in Faster R-CNN, classification and a single CNN is used for region proposals, instead of using the special region proposal method used in Fast R-CNN [5]. Similarly, YOLO proposed a new approach to object detection using a simple convolutional neural network, allowing to process images in real-time at 45 frames per second. Finally, SDD has comparable accuracy to methods that utilize an additional object proposal step, providing a unified framework for both training and inference. [6]

4.2. YOLO based Detection System

Considering the characteristics of the lift-car at which the internal conditions change from time to time, the accuracy of processing results, and the speed, we selected the YOLO(You Only Look Once) as the image detection technology. The image detection procedure using YOLO for our system is as follows [8].

(1) Generate image flame group sampling for analysis
(2) Runs a single convolutional network on the image
(3) Thresholds the resulting detections by the model’s confidence
(4) Moves the frame group and repeats the processing analysis

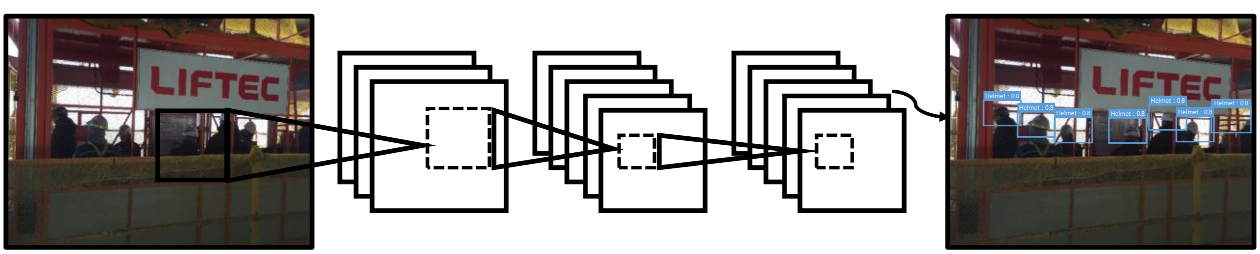

Fig. 6. YOLO Detection System

As shown in Fig. 6, the bounding box at each convolution network step calculate the reliability for the image. In initial step, the reliability of image can be low; however, by adjusting the position of the bounding box-the accuracy of object recognition can be improved. The YOLO-based image detection method has the following advantages through correction through repetitive frame movement.

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First, it can derive result faster since regression problem is used as detection method.
Second, comparing to other detection methods, the number of background errors rarely occurs.
Third, YOLO is highly generalizable, it is less likely to break down when applied to new domains or unexpected inputs.

4.3. Counting Manpower on the lift

The target for image detection is a helmet, to count the number of workers on the construction lift and the number of workers aboard each floor. Because all person on the construction lift wear the safety helmet, the helmet-targeted counting is more effective than counting the shape of a person.

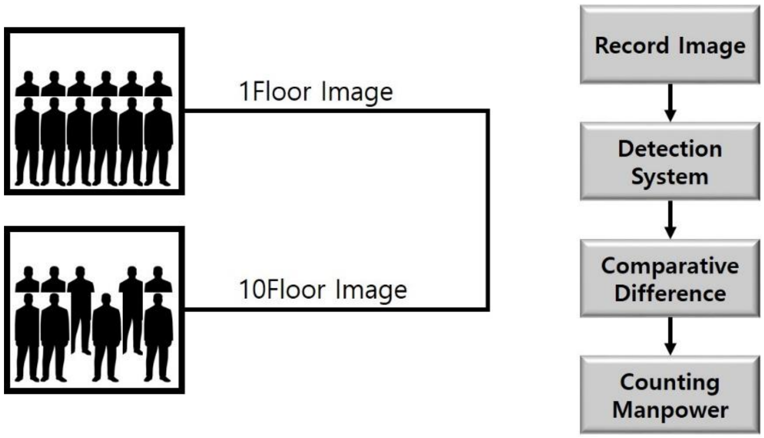

Fig. 7. Image Detection based Counting Method

As shown in Fig. 7, by comparing the number of passengers at the start of the lift and the status of the passengers after getting off a certain floor, it is possible to verify the number of passenger that got off in the floor. According to image detection based comparison, the data of how many workers have left at each floor could be collected and make lifting history of workers.

5. Adjustment Method of Finishing Work Schedule based on Image Detection

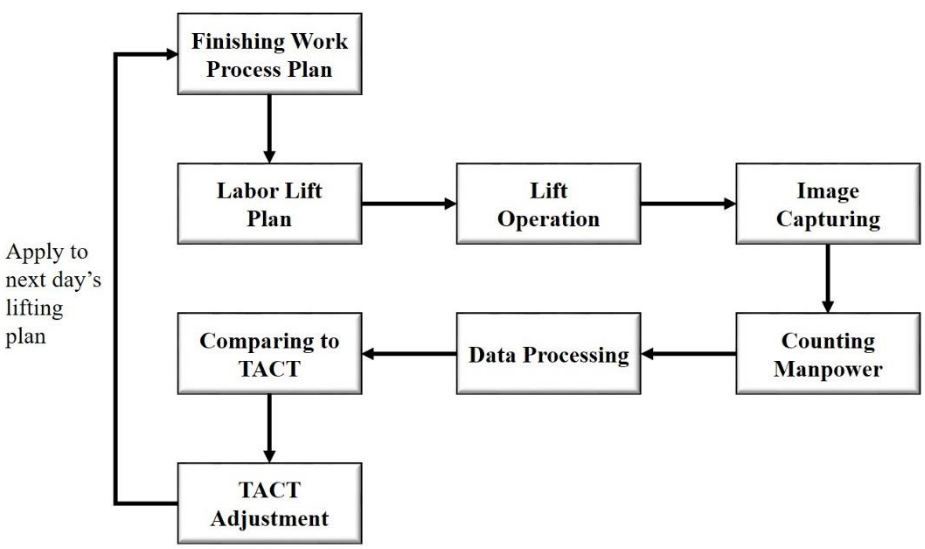

Fig. 8. TACT Adjustment Procedure

As shown in Fig. 8, it is possible to move to the planning stage with the existing planned TACT plan by composing the history of the getting off person from each floor. Because the TACT plan is based on the expected worker productivity for each task activity, the field manager can compare the plan and actual view from the short - term and long - term perspective by comparing the number of counting workers.

From a long-term perspective, the field manager can determine and correct whether the projected worker productivity is appropriate for the site, and from a short-term point of view, whether the work activity is delayed on the TACT process. If there is a delay in a particular activity, the field manager can adjust the time span by adjusting the TACT schedule.

In the short term, matching between image detection based labor management and TACT schedule is performed through the following procedure.

First, according to the planned process plan, the expected worker is placed on field.

Second, we collect and analyze information through lift manpower transport. And we acquire movement patterns of number of worker.

Third, TACT time is adjusted based on the expected schedule of the TACT process and the moving pattern of the actual number of worker.

Fourth, efficient manpower management is possible through the application of adjusted TACT time to the next day's process plan

6. Conclusion

As the buildings became high-risen, and the limits on the maximum lifted floors increased, variables applied to the management of finalizing construction became complicated. Hereupon, operation management of the lift is needed for the construction after implementing finalizing process along with a decision-making procedure on the transport-circulation of finishing work materials that are appropriate for flexibly changed situations in the field.

Therefore, in this study, operation history information by ip-camera was saved as image detection result. Then it was utilized to draw number of workers for each finishing work. Based on image detection technology and TACT technique, we proposed correction method to finishing work process management. Lastly, this study has served as a starting point of vision technology based lift-car management system. Therefore, it is anticipated to settle as a system based on unmanned smart lift through verification made in the entire period of research project.

Acknowledgement.

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Advantageous bridge construction with prefabrication

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Abstract

In comparison to the extensive period of time spent within the engineering and procurement stages, very short construction period is almost always required. The usual reasoning by the public highway agencies (i.e. project owners) for that is the effort to cut the construction costs, while the road user costs are usually ignored. This paper discusses the advantages of the prefabrication on the construction site over the traditional cast-in-place approach mainly regarding the speed of construction. Its advantages include the acceleration of construction due to parallel production of the lower structure and bridge's supporting structures, minimum impact on the existing transport network, i.e. lowering the road user costs to the possible minimum, better quality control, higher durability of the resulting structure and often also cost savings via the economies of scale. Paper further discusses the development of the bridge building with the usage of the prefabrication approach in the Czech Republic and how the system of prefabricated beams and segments have evolved till today. This newly improved way of building bridges has proved to be efficient even in the construction of the highway network's most demanding projects. Technological improvements, such as the use of high-quality concrete or new generation of prefabricated segments which provide new bridges with a long service life with minimal maintenance needs are assessed. Transferring the main construction activities after completion of the lower structure outside the bridged area is proposed. In a permanent production plant, high quality concrete elements can be achieved thanks to the high stiffness of the mold and considerable manufacturing accuracy. The classic method of constructing bridges with a medium span of mounting in symmetrical brackets from segments have successfully returned between frequently used technologies and especially the speed of construction gives this technology a good perspective to the future.

Keywords: precast concrete; prefabrication; segmental bridge; speed of construction.

1. Introduction

The current situation in the highway construction in the Czech Republic can be without any exaggeration defined as critical. The number of newly opened kilometres of highways stagnates at values of single digit of dozens. The construction of transport infrastructure is one of the long-term priorities of the Czech government and not even the financial crisis of 2008-9 and its many years lasting effects have not changed anything about it [1]. Although the impact of the crisis is still felt by the construction industry till today, money is not the problem regarding the highway construction, respectively governmental investments into it. After a very long period of time usually required for the approval of land use plans, verification of environmental performance, resolution of property relations and investment and project preparation, an extremely short construction period is almost always required. And bridges and tunnels are those objects that in particular limit the speed of construction. With the bridges of small and middle span, the prefabrication of the structural elements is the basic possibility how to deal with this requirement.

Precasting bridge parts and elements offsite is also very beneficial as bridges are generally among the most expensive objects constructed and also serve as a natural bottleneck for the traffic flows and so speeding up the construction process is beneficial again. It also brings substantial safety advantages, lowers disruption to traffic and increases overall convenience for the road users [2].

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2. Prefabrication of bridge constructions

The industrial production of concrete building elements can be applied to a significant part of the construction market. Prefabrication is a natural choice where high construction speeds are required where the auxiliary supporting structures coincide and formworks are for bridged transport routes and built or expensive land. While permanent factories with optimal work and the production conditions focus on simple or repeated standard designs; on the construction sites of large bridges, individualized molds for the production of large and heavy elements are needed [3].

2.1. Prefabrication on the site

The advantages of prefabrication on the construction site include the acceleration of construction due to parallel production of the lower structure and supporting structures, minimum impact on the existing transport network, better quality control and often also cost savings. Nevertheless, prefabrication at the construction site – unlike in other countries - has never started to be used much in the Czech Republic. Development in construction machinery and technology that uses heavy cranes, means of transport and assembly files, allowed extending of the prefabrication even to large bridges with melts and bridges with big spans, while maintaining its technical and economic advantages.

2.2. Possible negatives impacts

Prefabrication of bridge constructions can of course have negative impacts as well and careful consideration must always be given to the suitability of the system for any given environment. In particular, it is necessary to prevent monotone repetition, fine-tune the shape of the structures, solve the work and expansion joints and transfer of shear stress between individual elements.

3. Bridges using a system of prefabricated beams

Prefabricated composite beam systems are suitable for horizontal load-bearing structures of building structures and especially where considerable variability, fast construction without limitation of the underlying height, high payload and longevity are required. SSŽ (now Eurovia Group) construction company developed the systems of post-tensioned beams for the 12 to 27 m range and lightweight beams optimized for a 24 to 36 m, respectively for the 33 to 42 m range [4]. Bridge design is always optimized for each project with spatial arrangement, obliquity, continuity, load intensity, and other parameters. That is an important proof that the prefabrication expertise still remains in the Czech Republic, even though it is not being utilized in the same extent as it once was.

Supporting structures of beams with a coupled plate meet the current requirements of quality, durability and durability lifetime of the building work listed in european technical standards and in technical qualitative conditions. Beams are very suitable for different types of highway bridges and overpasses with a stand in the middle belt, but also for rail and tram bridges, pedestrian walkways, substructure of subways, excavated tunnels, underground garages and metro stations a heavily loaded ceilings of industrial buildings. The appearance of the bridges is aesthetically pleasing and design has a lighter look.

4. Segmental construction approach

4.1. Segmental technology limitations

Segment technology is world-class to significant technologies for the construction of medium-range concrete bridges. It is very demanding for technological equipment companies to its professional level and adherence to technological discipline. It is therefore not appropriate to use segment technology anywhere in common cases. A typical example is a high altitude above the terrain, inaccessibility of the area under the bridge, a large variation of the directional route of the small radii, high demands on speed and construction in last but not least, limitations of the wet construction process ecological reasons. It is necessary to take in consideration increased costs due in particular to higher tensioning stress consumption, and contractor's investment in technology equipment.

4.2. Necessary refinements

A large number of segmental bridges can be found, for example, in the Southwest and North Europe, North America or Southeast Asia. In the 70s and 80s of the twentieth century segment technology belonged to the most frequently used technology for the construction of bridges of medium range in the Czech Republic (and in former Czechoslovakia) and it was offered by most of the civil engineering contractors. Some of the then built segmental bridges, however, had to be costly reconstructed, especially due to insufficiently solved structural details in the project phase, lower quality of that era's materials and not fully dedicated and professional maintenance. Such improved segmental construction approach is being successfully used as can be seen on Fig. 1 below.

Fig. 1. Segmental construction approach applied at the D8 highway project in 2014. (Source: ŘSD ČR (Directorate of the roads and highways of the Czech Republic))

5. Innovation of the segment technology

5.1. Design's optimization

Above mentioned post-tensioned beams' system is built on the Freyssinet International system. Technological innovations made progressively on the basis of years of experience have eliminated the many shortcomings and problems in recent years. Great attention was paid to the deviators of the loose cord cables. In order to eliminate the risk of cracks in concrete after tensioning the cables, their shape, reinforcement and formwork technology have been optimized [4]. The free cable geometry is three dimensional in the implementation documentation and the conical outlets of the lifted cables are set in the exact direction, for example, by means of laser sighting. At the same time, optimization of the cable conduction, the bay reinforcement and the geometry of the internal prestressing channels are carried out during concreting. Furthermore, a complex of problems related to sealing of segments, watering of pockets and grouting of pretensioning cables was solved.

5.2. Design's modernization

The sealing of the cable ducts in the contact joints is solved by the determined technology of application of the certified putty in the joint. The injection and venting system has been optimized so that they do not pass through the seams between the segments, and the proposed pocket watering technology allows for perfect cavity filling. Complete renovation and modernization of molding techniques and assembly files were also carried out. A considerably complex problem of bridge behavior during construction is always solved by the designer on a spatial static model, considering the interaction between the foundation soil and the bottom structure. The calculation takes into account the progressive construction of the scaffolding over the pillars, their gradual joining and the influence of the rheological properties of the concrete and the filling of joints [5]. The aim is to minimize the differences between the theoretical level and the actual design of the load-bearing structure.

5.3. Design's lightening

The next phase of the innovation became generally used in practice after 2005. The visually lightened pillars with an X-shaped cross-section pass into an expanded head adapted to accommodate all the technological equipment for mounting and rectification of the load-bearing structure. Segments of the classic chamber cross section have rounded outer corners between the wall and the bracket. There is a maximum of one pair of bracket cables in each segment. The anchor is located in the area of the wall and the top plate, there are no cables in the walls. The result is small changes in the direction of the cable routing, thus improving the continuity of the cable path in the joints and evenly distributing the shear tooths along the entire height of the wall. Reducing the number of channels allows them to be sealed in seams with sealant. The above mentioned are actually only a part of all the currently applied innovations, just to prove the attention being paid to the possibilities of the prefabrication on the current market.

6. Conclusions

Beam bridges are being successfully used even at the long and heavy motorway estacades like the one on the D8 highway (see Fig.1) or on D3 highways in the Czech Republic [6]. The use of high-quality concrete provides these bridges with a long service life with minimal maintenance needs. Prefabricated beam structures of multiple fields are basically designed to be continuous. New generation of bridge segments of the Czech companies have proved its advantages even in the construction of the highway network's most demanding projects. Segmental technology is nowadays popular in the industry world-wide as for example around 500 segmental bridges have been built in the United States since the beginning of the 1970s [7]. The main advantage of the technology used is the high speed of construction - assembly takes place typically at a speed of four segments per day which is up to ten meters of bridge per day and as the segments are produced in advance, the assembly can keep up with construction of the lower structure.

Substantial differences can be also recognized with the prefabrication approach when comparing its life-cycle costs and an extent to which its construction process affects the public, environment and the local economy over the traditional cast-on-site construction. Prefabrication of any structure component off-site offers major construction time and user cost savings. Precast prestressed road pavements' technology and precasting bridges' parts and elements offers dramatic increase in durability, while it also substantially decreases construction time and resulting user costs [5]. High socio-economic importance of the road user costs is most often ignored by the public sector, i.e. by the project owner who decides its design. This can surely be identified as the main advantage of the discussed prefabricated segmental bridges and as a main recommendation to the state highway agencies together with the overall awareness about the road user costs importance.

Another benefit is the possibility of transferring the main construction activities after completion of the lower structure outside the bridged area (e.g. valley or a busy junction). In a permanent production plant, high quality concrete elements can be achieved thanks to the high stiffness of the mold and considerable manufacturing accuracy. The classic method of constructing bridges with a medium span of mounting in symmetrical brackets from segments have, after a certain decline, successfully returned between frequently used technologies and especially the speed of construction gives this technology a good perspective to the future.

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An assessment of construction procurement systems for public urban infrastructure projects

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Abstract

Project delivery systems play a significant role for the success of public urban infrastructure projects. Without clear and precise procurement selection techniques projects continue to contribute negatively towards infrastructure development. Therefore, the purpose of the study was to determine effective groupings of construction procurement systems for public urban infrastructure projects in South Africa. The data used in the study was derived from primary and secondary sources. Out of the 150 questionnaires distributed, 91 questionnaires were usable, representing 61% response rate. Data from the survey was analysed using exploratory factor analysis. Findings from the data analysis revealed that characteristics of traditional procurement system, develop and construct, management contracting and construction management should be incorporated for public urban infrastructure projects in South Africa. The study recommended that traditional procurement system, develop and construct, management contracting, construction management and project management continue to be utilised for public urban infrastructure projects. However, projects continue to fail as a result of these project delivery systems, therefore the study recommends that processes used to select project delivery systems should be clearly stipulated and dissected before the commencement of any project. Attention should be given to characteristics of different public urban infrastructure projects, as well as the forms of contracts incorporated.

Keywords: Project delivery systems; project success; public urban infrastructure; South Africa

1. Main text

Masterman [1] defines procurement systems as organisational structures used to execute construction projects suggested by the client, while Rameezdeen and Ratnasabapathy [2] explains procurement system as conditions and ways of successfully undertaking a project in order to achieve the objectives of the client. Public sector suggests appropriate procurement systems for the construction, maintenance and the rehabilitation of public urban facilities. Procurement systems are often categorised as traditional and non-traditional. Rashid et al [3] as well as Griffith and Sidwell [4] outline procurement systems currently used as: Design-Bid-Build; Construction Management at Risk; Design and Build; and Integrated Project Delivery.

Klynveld Peat Marwick Goerdeler (KPMG) International [5] and Love et al [6] explain that there are various procurement methods used for public urban infrastructure projects, therefore the client needs to understand all the available methods, their advantages and disadvantages to ensure that the project is finalised within the agreed time, cost and quality. Bijoy [7] further describes construction procurement as activities and techniques utilised to secure construction of a predefined system for an organisation, this includes organising the construction works and allocating risks to different stakeholders involved in a particular project. While UKESSAYS [8] reveals that, the choice of a particular procurement system fully depends on the type of project, type of ownership to take place, nature of the construction industry in a given country as well as the maturity of the industry.

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2. Construction procurement systems for public urban infrastructure projects

Oluwole [9] asserts that the completion of the construction project within the agreed time, cost and quality depends on the type of procurement system selected, hence the internal and external factors that influence the selection of a suitable procurement system [10]. Client's level of knowledge or experience and control, funding means, political and social concerns, understanding of the system, size of the project and technical complexity, quality and price certainty as well as risk allocation are internal factors considered [11]. Whereas external factors that need to be adhered to when a procurement system is selected include; market competition, technology, natural causes and regulatory environment [10].

2.1 Traditional procurement system

Options available under traditional procurement system include; bills of approximate quantities, bills of quantities, specification and drawings, schedule of rates, labour only and cost reimbursement. Traditional procurement method begins with a client brief, on what the client expects to be procured and other necessary specifications on cost. Architects and engineers are responsible for manufacturing designs [12]. Quantity surveyors are also involved in the design phase, where they advise on cost implications of the suggested designs [13]. Thereafter a contractor is appointed based on the designs that were computed by the design team, the client is thus in consensus with both the design team and the contractor. Turina [14] asserts that the design-bid-build widely known as the traditional procurement system is inclusive of three phases, which is the design phase, tendering phase and the construction phase, the process is sequential, the other phase cannot occur before the other one is complete.

2.2 Non- traditional procurement systems

Thwala and Mathonsi [11] elucidates that non-traditional procurement systems were developed to minimise the adversaries of traditional procurement system. Non-traditional system finds collective solutions for financial or political obstacles, further the system establishes common ground to put the design team and the contractor under a single roof in undertaking public urban infrastructure projects. Additionally, the system considers the functionality and management of the built structure [1].

2.2.1 Integrated procurement system (design and build)

Integrated procurement system is a single corporation providing the design as well as the construction services as asserted by Thwala and Mathonsi [11] as well as Ashworth and Hogg [15], the client does not have to get into contract with the design consultants then the contractor, the process of moving from one corporation to the other is eliminated by this procurement system. Rashid et al [3] reveals that it is ideal to use integrated project delivery, simply to share the risk amongst all the stakeholders involved that include designers, contractor as well as the client through partnership agreements.

2.2.2 Management procurement system

The client appoints a management organisation to provide the designs and manage the construction works, rather than having different organisations handling the designs as well as managing the construction works, during this form of procurement system the client is more involved as compared to other procurement systems [11]. Davies et al [16] asserts that a management organisation is appointed to handle all phases of the public urban infrastructure project, including the designs as well as the construction works. There are several kinds of management procurement systems: Design and management; Management contracting; and Construction management.

2.2.3 Construction management

The contract of works is direct between the client and the contractor, thus providing the employer larger control of the project. Subsequently, the employer has a larger control of the project the management contractor cannot determine

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when the project will be completed as well as what the final cost will be [17]. Thwala and Mathonsi [11] refers to CM procurement system as construction management at risk (CMR), the CMR acts as a consultant to the client during the design phase and as a contractor during the construction phase, during the construction phase the CMR ensures to deliver the project within the required time, quality and cost.

2.3 Public-private partnerships

Babatunde et al [18] discusses that public-private partnerships (PPP) are initiatives undertaken by the government to include private participation in delivering basic public urban infrastructure to various municipalities within a nation. While National Planning Commission [19] describes that PPP is a contractual obligation between the public and private sector, private firm agrees to construct and operate the built facility for a specified term.

3. Research methodology

Geographical area for the study was across South Africa. Targeted areas comprised of locations where the researcher had access to and where infrastructure projects were taking place or have taken place. The target population that replied the questionnaires was inclusive of the Department of Water and Sanitation, water boards, metropolitan, public entities (Trans-Caledon Authority Tunnel), civil society (eminent individuals/ corporations), building and construction professionals, private firms as well as banks who have financed water infrastructure projects in South Africa. A quantitative approach was undertaken for assessing construction procurement systems in South Africa. The study adopted a convenience sampling approach. 150 questionnaires were distributed, but 91 were usable, representing 61% response rate. Primary data was collected using close-ended questionnaires. The questionnaire had two sections, in addition to the cover letter. The duration to complete the questionnaire was 10 minutes. The first section presents the demographic information of the respondents while the second aspect details questions on construction procurement systems of public urban infrastructure projects. Statistical Package for Social Sciences (SPSS) was used for exploratory factor analyses.

4. Findings

4.1 Demographic information for respondents

Employment organisations for respondents revealed that building and construction sector was dominant with 23.1%, while public entities came second with 18.7%, metropolitans third with 13.2%, water boards fourth with 11% and the Department of Water and Sanitation last with 9.9%. Respondents' years of experience reveal that 45.1% had experience between 4-8 years, 28.6% had experience between 9-15 years and 19.8% had experience up to 3 years. From the 91 questionnaires used, 47.3% of the respondents participated or took part in water infrastructure projects, while the remaining 52.7% did not participate in any water infrastructure projects in South Africa. Respondents' involvement in water infrastructure projects show that 52.7% did not take part in any water infrastructure projects, while 14.3% participated in two (2) projects and 11% took part in three (3) projects.

4.2 Exploratory factor analysis for construction procurement systems

The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy achieved a value of 0.859, exceeding the recommended minimum value of 0.6, Bartlett's test of sphericity was also statistically significant (less than 0.05) with a value of 0.000, thus supporting the factorability of the correlation matrix, this is represented in Table 1. A total of 3 components with eigenvalues of above 1.0 were extracted using a factor loading of 0.5 as the cut–off point. The final components extracted accounted for 70.9% of the total cumulative variance, shown in Table 2. This is above the 50% threshold criterion for extracted factors to be explained in factor analysis. Varimax rotation was conducted to interpret the three components of construction procurement systems, which gave rise to the pattern matrix shown in Table 3. The components were labelled as a result of a close relation observed between the variables of each component. (i) Design and build options, (ii) management and (iii) labour and alliance, were labels given to each component.

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Table 1. KMO and Bartlett's test for procurement systems

Kaiser-Meyer-Olkin measure of sampling adequacy		0.859
Bartlett's test of sphericity	Approx.chi-square	1380.653
	Df	153
	Sig.	0.000

Table 2. Total variance explained

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	8.035	44.641	44.641	8.035	44.641	44.641	5.597	31.097	31.097
2	3.326	18.479	63.120	3.326	18.479	63.120	3.775	20.975	52.072
3	1.409	7.825	70.945	1.409	7.825	70.945	3.397	18.873	70.945

Table 3. Rotated Component Matrix[a]

Construction procurement systems	**Component**		
	1	2	3
Design and build options			
DBFT (design-build-finance-transfer)	0.841		
DBOT (design-build-operate-transfer)	0.839		
DBFO (design-build-finance-operate)	0.826		
BOOT (build-own-operate-transfer)	0.813		
OM (operation and maintenance)	0.786		
BTO (build-transfer-operate)	0.730		
JDA (joint development agreement)	0.676		
ROT (build-operate-transfer)	0.592		
Management Option			
Management contracting		0.936	
Develop and construct		0.911	
Construction management		0.885	
Traditional procurement system		0.748	
BOT(build-operate-transfer)		0.563	
Labour and Alliance			
Direct labour			0.824
Strategic alliance			0.780
Labour only			0.777
Investment management and investment services			0.711
BRT (build-rent-transfer)			0.561

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5. Discussion of findings

Thwala and Mathonsi [11] and Bijoy [7] support the findings that public-private partnerships contribute positively to infrastructure development, however the inclusion of project management and direct labour in the same cluster as PPPs was refuted by Olufowose [20] and Devapriya [21]. Babatunde et al [18] as well as Ashworth and Hogg [15] support the findings that items in component two when utilised contribute positively on infrastructure development. Rodriguez [22] as well as Seng and Yusof [23] highlight that traditional procurement system is still the preferred system to conduct infrastructure projects, it minimises tendencies of collusion as compared to other methods, studies further reveal that there are three kinds of contracts that exists, namely: lump sum contracts, measurement contracts and cost reimbursement. Akinola [24] adds that the use of traditional system alone does not always assure successful projects. Zhang and Wang [25], Thwala and Mathonsi [11] and Masterman [1] support the findings that the usage of public-private partnerships is significant for enhancing infrastructure investment. Babatunde [18] and Oluwole [9] share that procurement system selection is essential when selecting a suitable procurement system, time, cost quality are some of the key areas of the criterion. Rashid et al [3] shares that the usage of management contracting, develop and construct, construction management, traditional procurement system and build-operate-transfer have a fulfilling impact on conducting public urban infrastructure projects.

6. Implications

The level of usage of procurement systems such as traditional methods, design-build, management contracting, construction management and project management were rated amongst the most used systems in the construction industry for public urban infrastructure. Despite the level of awareness and usage of these procurement systems, projects continue to delay and ultimately fail as a result of cost overruns, exceeding the agreed time and not complying with quality standards. Therefore, the issue does not necessarily lie with the level of awareness or usage of these systems but how the processes are carried out, where the correct measures taken to select contractors, was the client consulted and whether the time given for procurement processes was adequate. Above all other procurement methods traditional system was the preferred project delivery system for public urban infrastructure projects.

7. Conclusion and recommendation

The results from the secondary data revealed that the procurement systems examined include traditional procurement system, develop and construct, management contracting, construction management, build-operate-transfer, build-own-operate-transfer, design-build-finance-transfer, design-build-finance-operate and joint development agreement. Other systems were inclusive of partnering, project management and strategic alliance. Findings from the questionnaire survey established three components of procurement systems were traditional procurement systems, develop and construct, management contracting, construction management, project management, partnering and build-operate-transfer were categorised in the same component. This confirms a strong relationship between the involved systems for public urban infrastructure projects in South Africa. Findings further confirms that construction project delivery system processes should be vigilantly adhered to, this includes the selection process of determining a suitable system to use for a given project. Attention should be given to characteristics of different public urban infrastructure projects, as well as the forms of contracts incorporated. The study was limited to water infrastructure projects across South Africa.

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An Integrated Multi-Attribute-Decision Making Approach for Selecting Structural System: A Case Study

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Abstract

A structural system is the essential component of a building, which carries all loads acting on the building and transfers them effectively to the soil through the foundation. The design team, which includes engineers and architects, is in charge of determining the most appropriate structural system that will fulfill the owner's and end user's requirements as well as the legal requirements. Selecting the most appropriate structural system is a difficult task as there are many factors that need to be taken into consideration. Therefore, this problem can be considered as a multi-attribute-decision-making (MADM) process. This study proposes an integrated MADM approach for solving this problem, which uses the analytic hierarchy process (AHP) and Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methods. In the proposed approach, AHP is used to find the weights of the criteria and VIKOR is used to rank the alternatives. The proposed approach was employed in a real case. Extensive review of the relevant literature was carried out and the face to face interviews were conducted with four engineers of the design team, which was responsible for the selection process of structural system in the studied case, in order to identify the criteria that may affect the selection of a structural system from the managerial perspective. A total of 5 main criteria, namely the durability and safety of the project, the energy consumption, the project characteristics, the total cost, and the constructability problems, and 19 corresponding sub-criteria were identified. The findings of this study revealed that the proposed approach can be a useful tool in selecting a structural system.

Keywords: AHP;VIKOR; multi-attribute-decision making; structural system selection; case study.

1. Introduction

A structural system must be able to perform the task of carrying all loads and transferring them safely to the soil through the foundation. Selection of the structural system, which can be considered as the skeleton of the structure, is one of the most important decisions as it determines the future of the structure [1]. In general, safety and aesthetics of a constructed facility depends on the selection of the structural system, which is selected by the design team, which includes engineers and architects [2]. The design team aims to determine the most appropriate structural system that will fulfill the owner's and users' requirements as well as the legal requirements [1,3].

In building projects, different material alternatives can be preferred in structural systems such as reinforced concrete, steel, precast, masonry, wood, composite, etc. Each material has pros and cons. For example, while wood buildings are light and relatively cheap, reinforced concrete buildings can resist wind loads, and steel structures allow large spans and resist seismic loads. Consequently, selecting an appropriate structural system is a difficult task as there are many factors that need to be taken into consideration [1,4-6].

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The objective of this study is to propose an integrated MADM approach for selecting the appropriate structural systems. For this purpose, first, an extensive literature review was carried out in order to determine the factors that may affect the selection of a structural system from the managerial perspective. After that, an integrated approach was proposed in order to assist the owner and design team in selecting the structural system from the managerial viewpoint. In the proposed approach, AHP is used to find the weights of the criteria and VIKOR is used to rank the alternatives. In order to illustrate how the proposed integrated approach can be applied in a real life project, a case study was carried out. The findings of this study revealed that the proposed integrated model can be used a useful tool in selection of the most appropriate structural system to make sound and reasonable decisions.

2. The Proposed Approach

The proposed approach includes eight steps, which can be classified under two main stages. The steps of the proposed approach are presented in Fig. 1.

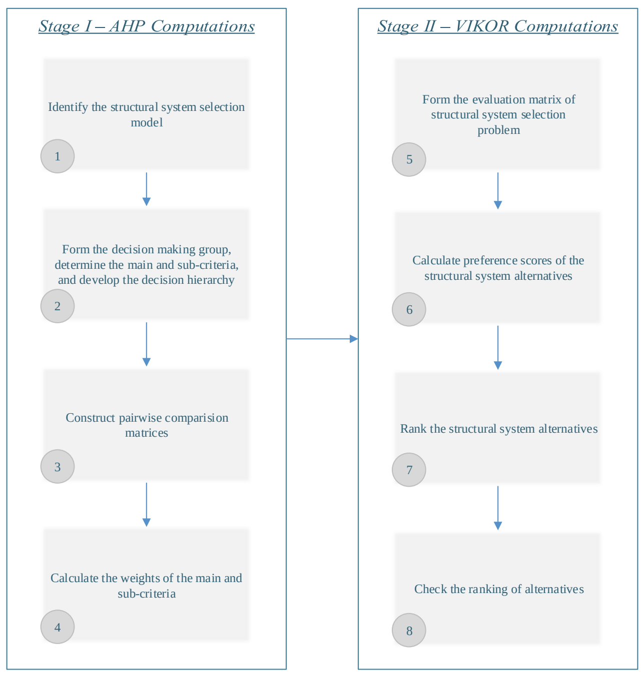

Fig. 1. The steps of the proposed approach.

In the first stage, the structural system selection problem is identified. Then, the decision making group, who are in charge of structural system selection in the construction company, is formed, and this group determines the main and sub-criteria that may affect the structural system selection and develops the hierarchy of the structural system selection model. Thirdly, the decision making group constructs pairwise comparison matrices of the structural system selection problem. In the final step of the first stage, the weights of the main and sub-criteria of the structural system selection problem are calculated by using the AHP method. In the second stage, first, the evaluation matrix, which consists of the assessments of the decision-making group members on the alternative structural systems, is formed. In the second step, the preference scores of the structural system alternatives are calculated by using the VIKOR method. Then, the structural system alternatives are ranked based on their preference scores in a descending order. Finally, the ranking of the alternatives is checked whether it meets the conditions of the VIKOR method.

2.1. Analytical Hierarchy Process (AHP)

The AHP is a mathematical theory developed by Thomas L. Saaty in 1980 to solve complex decision-making problems. AHP allows decision makers to model complex problems in a hierarchical structure that demonstrates the relationships among the problem's goal, main criteria, sub-criteria, and alternatives [7]. Since AHP is easy to

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understand by decision makers, it has been widely used in the literature and has been performed in almost all applications for multi-attribute-decision making in the last 35 years. AHP enables both objective and subjective opinions to be included in the decision-making process [8]. The calculation steps of AHP are explained below [9,10]:

Step 1: Defining the hierarchical structure of the decision problem (i.e., goal, main criteria, sub-criteria, alternatives).
Step 2: Constructing pairwise comparison matrices that allows numerical representations of relations between two elements in the hierarchy by using Saaty's Rating Scale (see Table 1).
Step 3: Calculating the consistency ratio indicating whether the matrices generated are consistent.
Step 4: Finding the priorities of the alternatives according to the main criteria and/or sub-criteria.

Table 1. Saaty's Rating Scale.

Intensity of importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the objective.
3	Somewhat more important	Experience and judgment slightly favor one over the other.
5	Much more important	Experience and judgment strongly favor one over the other.
7	Very much important	Experience and judgment very strongly favor one over the other.
9	Absolutely more important	The evidence favoring one over the other is one of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed.

2.2. Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR)

VIKOR method was developed by Opricovic and Tzeng in 2004 as a multi-attribute-decision making method to solve certain decision problems that are not measured by the same unit and have contradictory criteria. The method is an effective tool in multi-attribute-decision making, particularly in a situation where the decision maker is not able, or does not know to express its preference at the beginning of system design. This method provides compromise solutions for problems with contradictory criteria, by focusing on ranking and selecting on a set of specific alternatives. In this way, the method helps the decision makers to reach the final decision [11]. Compromise solution is obtained under the assumption that each alternative is evaluated for each criterion by comparing the values of proximity to the ideal solution. VIKOR method considers maximum group utility and minimum individual regret. The calculation steps of the method are quite simple and clear, which are briefly explained below [12]:

Step 1: Constructing the evaluation matrix X with n number of alternatives (n=1,….., i) and m number of criteria (m=1,….., j).
Step 2: Identifying the positive ideal solutions of n alternatives according to each criterion j (f_j^*) and the negative ideal solutions of n alternatives according to each criterion j (f_j^-).
Step 3: Normalizing the elements of the evaluation matrix.
Step 4: Computing S_i (the maximum group utility, which is the distance between alternative i and the positive ideal solution f_j^*) and R_i (the minimum individual regret of the opponent, which is the distance between alternative i and the negative ideal solution f_j^-).
Step 5: Computing Q_i (the VIKOR index for each alternative i, which is computed using the weight of the strategy of the maximum group utility q).
Step 6: Ranking the alternatives, sorting by the values of Q_i, in decreasing order.
Step 7: Proposing as a compromise solution the alternative (A_1), which is ranked the best by the measure Q_i (minimum), if the following two conditions are satisfied:

Condition 1. "Acceptable advantage"

$$Q(A_2) - Q(A_1) \geq \frac{1}{n-1} \quad (1)$$

where A_2 is the alternative with the second position in the ranking list by Q_i; n is the number of alternatives.

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Condition 2. “Acceptable stability in decision making”

Alternative A_1 must also be the best ranked by S_i or/and R_i. This compromise solution is stable within a decision making process, which could be: “voting by majority rule” (when $q > 0.5$ is needed), or by consensus” ($q \approx 0.5$), or “with veto” ($q < 0.5$).

If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of:

- Alternatives A_1 and A_2 if only Condition 2 is not satisfied, or
- Alternatives A_1, A_2,…, A_K if Condition 1 is not satisfied; and A_K is determined by using Equation 2 for maximum K.

$$Q(A_K) - Q(A_1) \approx \frac{1}{n-1} \tag{2}$$

The best alternative is the one with the minimum value of Q_i. The main ranking result is the compromise ranking list of alternatives, and the compromise solution with the “advantage rate”.

3. Case Study: Selecting the Most Appropriate Structural System

The proposed integrated structural system selection model was applied in a real case, which is a housing project in Istanbul, Turkey. This project consists of 3 basement floors, a ground floor, and 3 normal floors, and total construction area is 822,000 m^2. The structural system was selected based on the knowledge and experience of the design team, thus all of four civil engineers, who were responsible for the structural system selection, participated in developing this model. The model was developed based on their opinions and evaluations.

3.1. Decision Hierarchy of the Structural System Selection Problem

Having conducted face-to-face interviews with the design team members and carried out an extensive review of literature, 5 main criteria have been identified, which include: durability and safety (*DS*), energy consumption (*EC*), project characteristics (*PC*), total cost (*TC*), and constructability problems (*CP*). 5 sub-criteria under the main criterion *DS* are: resistance to external conditions (DS_1), resistance to seismic loads (DS_2), safety against fire (DS_3), resistance to wind loads (DS_4), and lifecycle of the structure (DS_5). 3 sub-criteria under the main criterion *EC* include: energy used to construct the structural system (EC_1), production energy of construction materials (EC_2), and reusability of construction materials (EC_3). 6 sub-criteria under the main criterion *PC* are: the number of floors (PC_1), need for large spans in the structure (PC_2), need for huge amount of clear space (PC_3), aesthetics of the structure (PC_4), changeability of the internal space (PC_5), and modularity of the structure (PC_6). 2 sub-criteria under the main criterion *TC* include: construction cost of the project (TC_1) and operation and maintenance costs of the project (TC_2). 3 sub-criteria under the main criterion *DC* are: construction duration (DC_1), delivery of construction materials to the site (DC_2), and availability of laborers and equipment (DC_3). The design team identified four different structural system alternatives, which are: reinforced concrete (*A1*), steel structure (*A2*), composite structure (*A3*), and precast construction (*A4*). The decision hierarchy of the structural system selection problem is presented in Fig. 2.

3.2. Determining the Weights of the Main and Sub-criteria of the Selection Problem

After constructing the decision hierarchy of the structural system selection problem, the AHP method is used to determine the weights of the identified main criteria and sub-criteria. For that reason, four decision makers were asked individually to construct pairwise comparison matrices for the main and sub-criteria of the selection problem. Four pairwise comparison matrices were then aggregated by taking the geometric means of each preference in order to reach a group decision. Finally, the mathematical calculations of the AHP method were applied to find the weights of the main and sub-criteria of the selection problem.

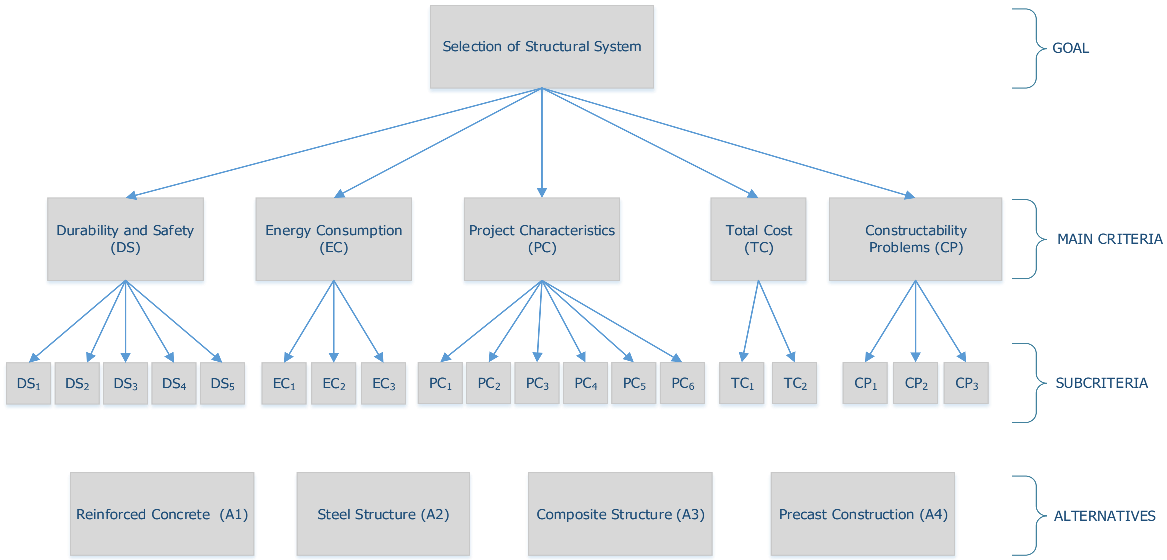

Fig. 2. Decision hierarchy of the structural system selection problem

Table 2 shows the weights of main criteria of the appropriate structural system selection problem.

Table 2. Aggregated pairwise matrix of main criteria for the structural system selection problem.

Criteria	DS	EC	PC	TC	CP	Weights	
DS	1.00	2.38	1.68	2.06	2.38	0.34	
EC	0.42	1.00	0.64	1.07	1.00	0.15	
PC	0.59	1.57	1.00	1.57	1.57	0.22	
TC	0.49	0.93	0.64	1.00	1.19	0.15	
CP	0.42	1.00	0.64	0.84	1.00	0.14	C.R. = 0.0020

According to the findings, the "*DS*-Durability and Safety" has the highest weight on the selection of a structural system problem. It is followed by the "*PC*-Project Characteristics" with second higher weight. On the other hand, the "*CP-Constructability Problems*" has the least importance on the selection process as it has the lowest weight. The consistency ratio (C.R.) of the aggregated pairwise comparison matrix is also checked. Since it is below the 0.10, it can be concluded that the evaluations are consistent.

The aggregated pairwise comparison matrix of five sub-criteria identified under the "*DS*-Durability and Safety" criterion is given in Table 3.

Table 3. Aggregated pairwise matrix of sub-criteria for the "*DS*-Durability and Safety".

Sub-Criteria	DS_1	DS_2	DS_3	DS_4	DS_5	Weights	
DS_1	1.00	0.45	1.41	2.21	1.68	0.20	
DS_2	2.21	1.00	2.83	4.76	4.00	0.44	
DS_3	0.71	0.35	1.00	1.68	1.28	0.15	
DS_4	0.45	0.21	0.59	1.00	0.76	0.09	
DS_5	0.59	0.25	0.78	1.32	1.00	0.12	C.R. = 0.0004

Based on the findings, the "DS_2- Resistance to seismic loads" has the highest weight among all sub-criteria. The aggregated matrix is also consistent (C.R. = 0.0004<0.1).

The aggregated pairwise comparison matrix of three sub-criteria of the "*EC*- Energy Consumption" criterion is given in Table 4.

Table 4. Aggregated pairwise matrix of sub-criteria for the "*EC*- Energy Consumption".

Sub-Criteria	EC_1	EC_2	EC_3	Weights	
EC_1	1.00	1.86	1.73	0.47	
EC_2	0.54	1.00	1.00	0.26	
EC_3	0.58	1.00	1.00	0.27	C.R. = 0.0005

Based on the findings, the "EC_1- Energy used to construct the structural system" has the highest weight. The aggregated matrix is also consistent since the consistency ratio is less than 0.1.

The aggregated pairwise comparison matrix of six sub-criteria for the "*PC*- Project Characteristics" criterion is presented in Table 5.

Table 5. Aggregated pairwise matrix of sub-criteria for the "*PC*- Project Characteristics".

Sub-Criteria	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	Weights	
PC_1	1.00	1.41	2.28	2.45	2.06	2.71	0.29	
PC_2	0.71	1.00	1.86	1.86	1.57	2.21	0.22	
PC_3	0.44	0.54	1.00	1.00	0.84	1.19	0.12	
PC_4	0.41	0.54	1.00	1.00	0.84	1.19	0.12	
PC_5	0.49	0.64	1.19	1.19	1.00	1.41	0.14	
PC_6	0.37	0.45	0.84	0.84	0.71	1.00	0.10	C.R. = 0.0003

Based on the findings, the "PC_1- The number of floors" has the highest weight. The aggregated matrix is also consistent (C.R. = 0.0003<0.1).

The aggregated pairwise comparison matrix of two sub-criteria identified under the "*TC*-Total cost" criterion is given in Table 6.

Table 6. Aggregated pairwise matrix of sub-criteria for the "*TC*-Total cost".

Sub-Criteria	TC_1	TC_2	Weights	
TC_1	1.00	1.41	0.59	
TC_2	0.71	1.00	0.41	C.R. = 0.0000

Based on the findings, the "C_1- Construction cost of the project" has the highest weight. The aggregated matrix is also consistent since the consistency ratio is less than 0.1.

The aggregated pairwise comparison matrix of three sub-criteria of the "*CP*-Constructability problems" is presented in Table 7.

Table 7. Aggregated pairwise matrix of sub-criteria for the "*CP*-Constructability problems".

Sub-Criteria	CP_1	CP_2	CP_3	Weights	
CP_1	1.00	2.83	3.72	0.62	
CP_2	0.35	1.00	1.32	0.22	
CP_3	0.27	0.76	1.00	0.17	C.R. = 0.0000

Based on the findings, the "CP_1-Construction duration" has the highest weight. The aggregated matrix is also consistent (C.R. = 0.0000<0.1).

3.3. Finding the Preferences of the Structural System Alternatives with VIKOR Method

After determining the weights of the main criteria and sub-criteria of the structural system selection problem, VIKOR method was employed to determine the ranking of four structural system alternatives. In the structural

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system selection problem, the preferences of four decision makers were collected to form the decision matrix. The data of "construction cost of the project" (TC_1) is quantitative and measured in Turkish Lira, whereas the other sub-criteria are qualitative and these values were obtained using 1 to 9 point scale (i.e., *1: Very Bad; 9: Very Good*).

In order to construct an aggregated decision matrix of the structural system selection problem, geometric means of the individual evaluations of the decision makers on the alternatives were calculated (see Table 8). In this selection problem, C_1 and C_2 are cost criteria where the smaller value is always preferred. The rest of them are beneficial criteria where the larger values are desirable. Therefore, TC_1 and TC_2 are minimized and the rest are maximized.

Table 8. Aggregated decision matrix of evaluation criteria for four structural system alternatives.

Criteria	Unit	Reinforced Concrete (A1)	Steel Structure (A2)	Composite Structure (A3)	Precast Construction (A4)	Weight	Opt. Dir.
DS_1	S.S	7.11	4.74	5.24	6.59	0.07	↑
DS_2	S.S	7.97	7.20	5.66	3.98	0.15	↑
DS_3	S.S	6.88	2.74	2.89	5.57	0.05	↑
DS_4	S.S	8.21	4.21	5.96	6.12	0.03	↑
DS_5	S.S	6.40	7.20	5.23	4.86	0.04	↑
EC_1	S.S	7.48	6.40	6.40	5.89	0.07	↑
EC_2	S.S	5.89	7.17	6.90	6.16	0.04	↑
EC_3	S.S	2.99	6.88	5.69	4.46	0.04	↑
PC_1	S.S	6.09	6.45	4.56	6.16	0.06	↑
PC_2	S.S	5.38	7.97	4.90	7.14	0.05	↑
PC_3	S.S	6.74	4.74	8.00	7.97	0.03	↑
PC_4	S.S	6.59	7.17	6.85	5.96	0.03	↑
PC_5	S.S	5.21	4.24	4.05	3.98	0.03	↑
PC_6	S.S	1.86	5.58	5.18	6.59	0.02	↑
TC_1	$x10^3$ TL	335	795	650	720	0.09	↓
TC_2	S.S	4.16	7.90	6.05	5.24	0.06	↓
CP_1	S.S	5.00	7.09	6.62	6.51	0.09	↑
CP_2	S.S	6.51	5.63	5.38	4.68	0.03	↑
CP_3	S.S	7.33	5.38	5.48	4.95	0.02	↑

*S.S.: Subjective Score

After forming the aggregated decision matrix, the steps of VIKOR method were followed. First, the best f_j^* and the worst f_j^- values of all criteria were determined (see Table 9).

Table 9. Aggregated decision matrix of evaluation criteria for the four structural system alternatives.

	DS_1	DS_2	DS_3	DS_4	DS_5	EC_1	EC_2	EC_3	PC_1	PC_2	PC_3	PC_4	PC_5	PC_6	C_1	C_2	DC_1	DC_2	DC_3
RCC	7.11	7.97	6.88	8.21	6.40	7.48	5.89	2.99	6.09	5.38	6.74	6.59	5.21	1.86	335.00	4.16	5.00	6.51	7.33
SS	4.74	7.20	2.74	4.21	7.20	6.40	7.17	6.88	6.45	7.97	4.74	7.17	4.24	5.58	795.00	7.90	7.09	5.63	5.38
CS	5.24	5.66	2.89	5.96	5.23	6.40	6.90	5.69	4.56	4.90	8.00	6.85	4.05	5.18	650.00	6.05	6.62	5.38	5.48
PC	6.59	3.98	5.57	6.12	4.86	5.89	6.16	4.36	6.16	7.14	7.97	5.96	3.98	6.59	720.00	5.24	6.51	4.68	4.95
f_i^*	7.11	7.97	6.88	8.21	7.20	7.48	7.17	6.88	6.45	7.97	8.00	7.17	5.21	6.59	335.00	4.16	7.09	6.51	7.33
f_i^-	4.74	3.98	2.74	4.21	4.86	5.89	5.89	2.99	4.56	4.90	4.74	5.96	3.98	1.86	795.00	7.90	5.00	4.68	4.95

Then, the normalized decision matrix was computed. After that, the values S_i, R_i, and Q_i of four structural system alternatives were calculated. Finally, four structural system alternatives were ranked by Q_i values in decreasing order. The result matrix is shown in Table 10.

Table 10. Result matrix of VIKOR method.

Alternatives	S_i	R_i	Q_i	Ranking	Checking Conditions	
A1	0.276	0.086	0.000	1.00	C1. 0.309 < 0.333	×
A2	0.469	0.089	0.309	2.00	C2. A1(R_i) = min(R_i)	✓
A3	0.614	0.087	0.507	3.00		
A4	0.614	0.150	1.000	4.00		

Based on the ranking results, although A1 (reinforced concrete construction) is the best alternative with minimum Q_i value, A1 and A2 (steel structure) are compromise solutions because A1 does not satisfy the "acceptable advantage" condition. According to the ranking results, A3 (composite structure) and A4 (precast construction) ranked third and fourth, respectively. The outcomes of proposed model were discussed with the decision makers and the construction company preferred A1 as the structural system in real life. They stated that they had mostly selected the structural system based on one single criterion, namely cost, and had not considered other factors. They concluded that they could employ the proposed model in future to make sound decisions.

4. Conclusions

Selection of an appropriate structural system is a difficult task in design phase as there are many factors that need to be taken into consideration. An extensive literature review was carried out in order to identify the factors that may affect the selection of a structural system from the managerial perspective. This study proposed an integrated model for selecting the most appropriate structural system. Two multi-attribute-decision-making methods, namely AHP and VIKOR, were integrated to find the most appropriate structural system option among the alternatives. In the integrated model, the AHP method was used to determine the weights of the identified main criteria and their constituent sub-criteria. The VIKOR method was used to determine the ranking of the structural system alternatives. In order to demonstrate how the proposed integrated approach can be performed in a real life project, a case study was carried out. The finding of the proposed integrated model was discussed with the decision makers, who participated in this study. This study revealed that the proposed integrated model can be utilized as a guideline in selecting the most appropriate structural system from the managerial viewpoint.

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An investigation of leadership styles of construction professionals in the South African construction industry

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Abstract

The South African construction industry has a bearing on the economic abundance of the country. Consequently, maximum productivity is required; and to achieve this, proper leadership is one of the major factors that are needed. Literature suggests that there is huge leadership challenge among project leaders and professionals. However, little prominence is been given to the leadership competence of construction professionals in South Africa and other developing countries especially in practice. The main objective of this paper is to investigate the predominant leadership styles among construction professionals in the South African construction industry. The primary research data were collected through a structure questionnaire survey conducted on construction professionals in the Gauteng Province of South Africa. The secondary data were collected from literature review. Respondents were selected using heterogeneity and convenience (purposive) sampling techniques. Data from the questionnaire were analyzed using Statistical Package for the Social Sciences (SPSS) version 22.0 software. Mean values and standard deviation were computed. The rank of the predominant styles among the identified construction professionals was established. Findings from the study revealed that the three leading predominantly used leadership styles among construction professionals are democratic, transformational and transactional leadership styles. In addition, the results revealed the predominant leadership styles used among each construction professionals in the South Africa. The study contributes to the body of knowledge by increasing awareness about the essential of leadership and the proper use of its styles at any given circumstance within the South African construction industry.

Keywords: Construction industry; leadership style; construction professionals.

1. Introduction

Innovation and improvement in project delivery are becoming the prime focus of developing countries in Africa especially South Africa [5]. There has been an improvement in the recognition of new ideas, and quest for creativity. Conversely, leadership skill which is one of the vital tools for effecting change still receives less attention than technical skill. As a result, the construction industry has suffered many leadership challenges and gaps including slowness in adapting to change, unpreparedness to uncertain future, and inappropriate implementation of strategic planning to mention but a few [17].

Leadership is essential in everyday life, in our families, schools, health sectors and organisations such as the construction industry. Without competent leadership people do what seems right in their own eyes; moving like sheep without a shepherd. Incompetent leadership is one of the reasons for inadequacy in balancing operational and strategic pressures even the managing of workloads [27]. On the other hand, proper leadership in any organisation

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helps mitigate wastage of resources especially time, labour and money while upholding quality of work in general. Leadership even goes a long way in maintaining staff morale and engagement. This is because it entails the support of an individual to a group of people in all the essentials necessary to the attainment of the set goals [1].

The subject - Leadership is challenging in the construction industry considering the nature of the environment which is a product of complex and changing situations [25]. In addition, the fact that human beings behavior and culture differ makes the value of this subject very crucial [3,25]. Hence, it is vital for a leader to have a proper understanding of the appropriate leadership style to adopt in order to adequately influence his or her subordinates. Research has been conducted on leadership styles in the construction industry [1,17,25,31]. Previous studies have focused mainly on project managers, construction managers and quantity surveyors [17,25,31]. Less attention has been paid to the styles of other professionals who participate and even lead in their various fields towards the timeous completion of construction projects [1]. To this effect, this paper investigates the predominant leadership styles among construction professionals in the South African construction industry.

2. Leadership in the construction industry

The competency of leadership has been the subject of much debate in the construction industry [1,25]. There are still some doubts whether the industry has enough leaders who can inspire and affect real change [33]. This is because; there is a need for the industry to rise above social, economic and environmental challenges prevalent in our society today. It is evident that the construction industry by its disposition is one of the industries that need leadership in its purest form; and with much emphasis on project management systems nowadays, a better management and leadership skills need to walk in tandem [14]. It is also an industry where everybody is expected to take responsibility whether one is a follower or not [1,30]. This is true with the saying; "trapped in any follower is a leader". Even the leaders are expected to lead themselves first. In addition, Toor and Ofori [33] noted that leadership disposition includes factors such as personal traits, ability to give clear information and the know-how of situational variables in operation. Therefore, in a project team, the construction professionals involved must take responsibility and apply the principles of leadership toward having a successful project delivery.

2.1 Leadership styles of construction professionals

Leadership by definition is more about influence [19]. This is in harmony with the saying that "He, who leads and has no one following, is only taking a walk". However, people will not follow a leader effectively without a proper application of leadership styles. Attitudes and behaviours when consistently combined in dealing with subordinates are point notes for the discovery of a leader’s style of leadership [30]. Therefore, a leader is defined by the style he portrays [10]. Hence, Leadership style can be defined as the prevalent and consistent behavioural pattern of a leader [10]. It is the predominant behavioural pattern a leader uses in his or her effort to increase his or her influence on the subordinates [22]. However, knowledge of the environment and circumstances, and the understanding of people's behaviours and values are essential [3]. Hence, effective leaders vary their leadership style base on their context and followers’ attribute [8]. Leadership, therefore, is very important in any undertaking where collaboration of the individuals is required such as in construction [25]. From the construction industry perspective, literature has revealed some perceived traits of leadership style of which includes, inspiration, motivation, rewards consciousness [18,30]. The following leadership styles that are predominantly used among leaders are hereby discussed below.

- Authoritarian leadership

Autocratic leaders as popularly known, self-confidently make decisions with the assumption that the subordinates will comply without any objection [11]. Autocratic leaders are popularly known to be work-centred because their major aim is to get things done and on time [27]. They set agendas as well as the modus operandi of the group and its policies; the give work to subordinates without first consulting them [11]. Authoritarian leadership is advantageous especially when there is a need to make a quick decision and execute a task in any undertaking [10]. However, the abuse of this leadership style is often problematic as it is often perceived as being bossy and dictatorial and domineering of which can install grudges among subordinate [30].

- Democratic leadership

This is the opposite of authoritarian leadership style. It involves the engaging of group members in the decision making and working in tandem with them [18]. Leaders using this style confer final authority on the group; decisions are not solely made by the leader [17,30]. In other words, democratic leaders focus on gathering the group opinions and then voting for final approval [10]. This style is suitable for personnel who appreciate getting involved in decision-making in an organisation. It is advantageous because it meets one of the Maslow's hierarchies of needs of employers as it boosts self-esteem [17].

- Laissez-faire leadership

Leaders who possess this style of leadership are characterized as being uninterfering with their subordinates [17]. In other words, the leader has no real authority but allows the group to perform based on their own decisions [4]. Laissez-faire style thrives in environments with highly skilled and self-motivated followers [18]. Therefore, the function of a laissez-faire leader inter alia is to ensure that highly skilled and trustable individuals are brought into the organisation [17,18].

- Transactional leadership

The primary aim of the leader with this style of leadership is to meet the need of the present condition and see to it that the organisation is run in an efficient manner [6]. A transactional leader first understands the subordinates' needs and clarifies how their desires can be met based on the fulfilling of conditional requirements [6,10]. In other words, transactional leadership style basically is centred on the barter between leaders and their followers [23]. This exchange can be in the form of incentives, increased remuneration or time off which serve as a motivation to the employees to perform more than expected.

- Transformational leadership

Per Daft [6] transformational leadership is much more concentrated on that of a leader's personal attributes, values and belief system rather than transactional relationship between the leader and follower. These leaders can inspire and lead changes in an organisation's visions, policies and affairs [6,10]. They present themselves as role models for employees, motivate them, stimulate their intelligence, help raise subordinate awareness and help subordinates understand the need for change [30].

- Strategic leadership

Strategic leadership focuses mostly on individuals at the top of an organisation and their effects on strategic processes and results [7]. It is believed to be the most appropriate style of leadership for organisations implementing corporate and social responsibility strategies [28]. The duty of a strategic leader is to inspire others to take the appropriate action while having in mind the best interest of the business and the people [28]

- Charismatic leadership

The word charisma is derived from a Greek word which means *divinely inspired gift* [10]. To have charisma in general is to have an attractive personality [10]. This personality inter-alia is the fire that lights up the subordinates to perform even more than required [30]. These leaders can influence their subordinate emotionally as well as inspire them for maximum input, irrespective of obstacles in the way [10,30]. The leaders are mission driven people and are positive about the attainment of the vision; and because of these; they are able to influence those around them to buy in their purpose [6].

2.2 Leadership styles in the Construction industry: global and South African experience

Leadership style of a leader can be influence by national, environmental or organizational culture [15,34]. For instance, it would be difficult to act in a more democratic style in a culture that value autocratic leadership. However, in a culture that is relationship oriented, being sensitive and considerate as a leader could thrive well [15]. In United Kingdom (UK), the Leadership styles used in their order of importance are strategic, democratic, Charismatic and transformational (28). In South Florida, the leadership styles of most construction professionals are high task oriented. However, just like other western countries they never negate the fact that a good working relationship between the leader and the subordinates are essential [29]. Western leaders not only focus on building teamwork, interpersonal bonds, dignity and trust, but also they are highly entrepreneurial and are inclined to taking risks thereby differentiating themselves from their counterparts [30]. Conversely, in Hong Kong and China, where the culture is highly related, leaders prioritise the maintenance of a good working relationship more than getting the job done [30,32]. However, for subordinates on construction site, transformational leadership style is primarily used and secondarily supported with transactional style [32]. In United Arab Emirates (UAE) transformational leadership style is the most used leadership style [9]. In addition, many construction leaders also adopt consultative or participative (democratic) leadership style [35]. In Indonesia and Nigeria, the project leaders and managers are task oriented when initiating projects with their workforce [2,26]. Furthermore, Oke [26] affirmed that the Nigerian construction industry is dominated with autocratic style of leadership. However, in Ghana the predominant styles used by the construction and project managers are transformational and transactional leadership. Finally, for South Africa, leadership culture is that of "Ubuntu", *Meaning* - a culture of acceptance, showing compassion, and tolerance [16]. In addition, leadership participation is mostly shared by the members rather than invested in one person [16]. Hence, the Leadership culture in South Africa is dominated with democratic, transformational and transactional style.

3. Research methodology

A quantitative approach was adopted in this research. This is because it is a scientific method which reduces complexity and simplifies situations to the point where they can be examined measured and tested [12]. It is one of the cost-effective ways to collect data from many respondents [20]. Hence, 5-point Likert-scale survey questionnaire was constructed from the literature review of leadership styles. It also accommodated a descriptive survey because of the exploratory nature of this research. A convenience (purposes) sampling was used, targeted at construction professionals in the Gauteng Province of South Africa. This is due to the relatively large number of construction companies in the province. The professionals were limited to project managers, architects, quantity surveyors, construction managers, civil engineers and town planners. 51 questionnaires were recovered out of a total of 81 distributed (63% response rate). Data were analyzed using the Statistical Package for Social Sciences (SPSS) version 22.0 software. The reliability and internal consistency of the collected data was appraised using Cronbach's alpha α. The α value for the leadership styles was 0.79. Outputs were mean (M) and standard deviation (SD) values. Weights were assigned to each response ranging from 1 to 5 from "strongly disagree" to "strongly agree". The rankings of the predominantly used leadership styles of the various professionals were also assessed base on the mean values.

4. Findings and discussions

The findings centred on the five major leadership styles revealed from literature and portrayed in Table 1. The findings showed that Democratic leadership was ranked first with average mean score (AMS=4.29) and standard deviation (SD=0.14); Second was transformation leadership style (AMS=4.21, SD=0.26); third was transactional leadership (AMS=4.02, SD=0.19); laissez-faire leadership was ranked fourth (AMS=3.97, SD=0.27); and lastly the autocratic leadership style (AMS=3.05, SD=0.21).

Table 1. Predominant leadership styles among construction professionals in the South African Construction industry

Leadership styles	Mean	Standard deviation	Rank
Democratic leadership	4.29	0.14	1
Transformation leadership	4.21	0.26	2
Transactional leadership	4.02	0.19	3
Laissez faire leadership	3.97	0.27	4
Autocratic leadership	3.05	0.21	5

Table 2 revealed that for the project managers, the average mean scores of all the leadership styles were above 3 out of 5 except the autocratic leadership style which had average mean score (AMS=3.0). Indication showed that laissez-faire leadership style was the predominantly used leadership style among project managers (AMS=4.28); followed by democratic leadership style (AMS=4.23); while transactional and transformational leadership style have AMS of 4.13 each. However, autocratic leadership was ranked last (AMS=3.0).

Findings on the construction managers revealed that all the leadership styles exceeded the standard average mean score of 3.0. Democratic leadership style was predominant (AMS = 4.34); followed by transformational leadership (AMS=4.16); third, transactional leadership (AMS=4.09); fourth, laissez – faire leadership style (AMS=3.91) and fifth, autocratic (AMS=3.38).

Table 2: Leadership styles among each professionals in the South African Construction industry and their mean rankings

Professionals	1	2	3	4	5
Project manager	Laissez faire (4.28)	Democratic (4.23)	Transactional (4.13)	Transformational (4.13)	Autocratic (3.00)
Construction manager	Democratic (4.34)	Transformational (4.16)	Transactional (4.09)	Laissez-faire (3.91)	Autocratic (3.38)
Architect	Democratic (4.08)	Transformational (3.86)	Transactional (3.66)	Laissez faire (3.62)	Autocratic (2.76)
Quantity surveying	Transformational (4.27)	Democratic (4.22)	Transactional (4.18)	Laissez faire (3.72)	Autocratic (3.03)
Civil engineering	Transformation (4.66)	Democratic (4.40)	Laissez faire (4.22)	Transactional (4.11)	Autocratic (3.17)
Town planner	Democratic (4.46)	Transformational (4.17)	Laissez faire (4.03)	Transactional (3.94)	Autocratic (2.98)

Findings regarding the architects revealed that all the leadership styles obtained an AMS of more than 3 out of 5 except autocratic leadership styles. Democratic leadership majoring with (AMS =4.08); second was transformational leadership (AMS=3.86); third, transactional leadership (AMS=3.66); fourth, laissez-faire (AMS=3.62) and lastly autocratic (AMS=2.76).

Findings regarding the quantity surveyors portrayed that all the five leadership styles obtained an AMS of more than 3.0 out of 5.0. Transformational leadership style was ranked first (AMS=4.27). Democratic leadership style was ranked second (AMS=4.22); third was the transactional leadership style (AMS=4.18); while laissez-faire and autocratic leadership styles was ranked fourth (AMS=3.72) and fifth (AMS=3.03) respectively.

Findings from the civil engineers indicated that all the five leadership styles possessed an AMS of above 3.0 out of 5.0. Transformational leadership was also ranked first (AMS=4.66); followed by democratic leadership style (AMS=4.40); third was laissez-faire (AMS=4.22); while transactional and autocratic leadership occupied the fourth and fifth position with (AMS=4.11) and (AMS=3.17) respectively.

Finally, findings from the Town Planners revealed that all the various leadership styles obtained an AMS of more than 3.0 out of 5.0 scale except for the autocratic leadership style which was ranked last (AMS=2.98). Democratic leadership was ranked first (AMS 4.46); transformational leadership was ranked second (AMS=4.17); third was laissez-faire leadership (AMS=4.03); while transactional and autocratic leadership were ranked fourth and fifth with (AMS=3.94) and (AMS=2.98) respectively.

In general, based on the findings of table 1, laissez faire and autocratic leadership are on the downside when it comes to its influence on people to achieve the desired goal in South Africa. This finding is in agreement with that of liphadzi [18] relationship between leadership styles and project success. However, it is vital to note that the success of construction professionals in leading their subordinates effectively lie in their adaptive approach to any given situation and the utilisation of the leadership style that best suits the given situation or project [21].

5. Conclusions

The study set out to establish the predominant leadership styles of construction professionals in the South African construction industry. Findings revealed that democratic, transformational and transactional leadership were the leading leadership styles in the South African construction industry. It also revealed that laissez faire and autocratic leadership styles were the lowest used styles among construction professionals in the South African construction industry. It further revealed the predominant preferred styles among each of the mentioned professionals in their rankings.

The study provides useful insight on the issue of leadership styles in South African construction industry of which will help the various professionals identify their styles as well as discover areas they should improve on. This is because a particular leadership style won't get the entire job done. Hence, appropriate implementation of leadership styles will help mitigate unnecessary conflicts, increase productivity within the organisation as well as improve the Gross Domestic Product of South Africa.

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Analysis of Improvisation in Construction Through Agent-based Modelling

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Abstract

Improvisation is rational and decisive, deterministic and emergent, but impulsive and fuzzy. While the results of improvisation are perfectly understandable after the fact, the decision process is spontaneous in its making. Improvisational practices continue to exist within numerous construction operations where unforeseen uncertainty cannot be fully avoided. Therefore, a construction project will greatly benefit from applying an adaptive planning system that employs improvisation and hence reacts rapidly and wisely in case of unplanned or newly emerging problems. This study aims at developing a simulation model that depicts the improvisation process at the level of planners associated with different construction trades and identify different influencing factors. First, after attaining a thorough understanding of the process based on previous research studies, agent-based modelling is used to model the improvisation process that occurs at the level of each agent (planner), as well as the interaction processes that arise between the agents and the environment (construction project), and among the agents themselves. The simulation model takes into consideration several types of parameters that highly influence how each planner improvises. These parameters are planner-related, project-related, as well as problem-related. The contribution of this study lies in developing a better understanding of the improvisation mechanism within construction as well as identifying the impact of various types of influencing factors on the overall improvisation performance. Future research is recommended to better enhance the practices of improvisation for different construction projects.

Keywords: improvisation; construction; agent; planners.

1. Introduction

Planning in construction is an indispensable process that spans throughout the project's life cycle and aims to achieve the project's objectives related to time, cost, quality, and safety. Planners and schedulers have always highlighted the importance of planning for organizing work, reducing risk, facilitating communication, maintaining good control, as well as reaching their desired objectives [1]. Unfortunately, traditional planning practices cannot develop plans and procedures for all possible scenarios and eventualities [2]. Therefore, improvisation may turn out to be the final resort for addressing the issues of uncertainty, dynamism, and complexity [3].

Improvisation has recently gained a wide interest in the field of organizations as it significantly contributes for better managing the problems of unforeseen uncertainty [4]. Numerous organizations have relied on improvisation to deal with unplanned interruptions and compensate for the limitations of traditional planning and improper management [5, 6]. Therefore, understanding the dynamics of improvisation has become a necessity to survive in dynamic, complex, and/or uncertain organizational environments. Improvisation is the act of formulating a decision or performing an

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action without having the optimal resources and/or information [7]. It helps decision-makers to make their decisions at the spot, without having the luxury of preparation [4]. Accordingly, researchers have demonstrated the practices of improvisation in different organizational settings and looked at different fields of application to analyze the process.

Due to their increasing levels of complexity, construction projects have been characterized with interdependent types of uncertainties [8, 9]. Accordingly, one of the main issues that face planners in construction is the inability to stay on the right track during the construction phase due to uncertainty, improper planning, and unforeseen conditions. As a result, construction literature has introduced new procedures into planning to efficiently reduce the problems of uncertainty and variability. The Last Planner System (LPS) is developed to manage foreseen or expected uncertainties. It supports planning with greater detail as execution is approached so that constraints are removed prior to execution or construction [10]. However, a complex environment requires improvisation as a complementary practice for planning since it helps planners and decision-makers handle unplanned incidents which are unavoidable in any work environment [4, 7].

Improvisation in construction is an interesting practice to cater for the dynamism and the glitches resulting from unexpected uncertainty. However, few contributions are made in the literature to explain improvisation in the context of construction operations. The aim of this study is to better manage the unforeseen uncertainties in construction through analyzing the process of improvisation at the level of different planners within a certain construction endeavor and identifying the linkages between the overall improvisational outcomes and different project and planners-related factors. This research employs agent-based modeling to develop a simulation model that depicts the improvisational practices within a construction project. This paper entails a literature review of the improvisational practices in organizations and construction as well as background information about agent-based modelling. Then, the methodology of the study is explained, and the conceptual framework along with the agent-based model is presented. Finally, the paper encloses with a set of conclusions and future research works.

2. Background

2.1 Improvisation in organizations

Improvisation in organizations has been analyzed through looking at different perspectives. Innovation, creativity, and spontaneity have always accompanied the definitions of improvisational practices in organizations [11]. On the other hand, several researchers have looked at improvisation as a supportive practice that links between traditional plans and unforeseen situations [12]. Another approach for analyzing improvisation has focused on the method followed while improvising; improvisation is mainly re-combining the existing conditions, routines, and resources to manage unplanned situations [13]. In addition, as a general definition, improvisation is "the conception of action as it unfolds, by an organization or even one of its members, drawing on available material, cognitive, affective and social resources" [14].

Recent studies have considered improvisation as an essential performance variation that should be employed in rapidly changing and/or uncertain environments [4]. However, the possibility of generating accidents while improvising at operational work has been documented in the literature; hence, showing the need of advancing the knowledge of improvisation prior to start practicing [15]. Therefore, organizations have focused on analyzing the process of improvisation and studying its different influencing factors so that it's properly practiced. For instance, Trotter et al. (2014) have analyzed the application of Rasmussen's (1997) Risk Management Framework and Accimap methodology for identifying the influencing factors of improvisation in critical safety situations [16]. Moreover, some researchers have studied the appropriateness of improvisation for competing with other organizations through better responding to unexpected market conditions [17].

Different influencing factors of improvisation has proven to be crucial while analyzing or predicting the improvised outcome. These factors involve: experience, education, training to improvise, teamwork, collaboration, situation awareness, information flow, organizational structure, organizational memory, organizational culture, and authority mitigation [3, 18]. Besides of its influencing factors, improvisation has been described by a set of characteristics to assess its degree such as speed, novelty of input, and time pressure [3, 6, 14]. Also, the severity of improvisation has been portrayed as a continuum; it starts with interpretation, then proceeds to embellishment that's followed by variation, and finally ends up with improvisation [14].

2.2 Improvisation in Construction

Project control methods have gone through tremendous improvements with the aim of optimizing different performance indices, managing variability as well as catering for uncertainties. The Last Planner System is one of the control methods that intends to increase planning reliability and improve the project's overall performance by planning at different levels of detail during the construction phase. The LPS focuses on the quality criteria prior to execution of the tasks in order to avoid deviations resulting from uncertainty and/or improper planning [19].

Failures during construction have been classified into three categories [20]. The first category involves failures in executing planned tasks due to deficiencies in identifying constraints and removing them on time. The second category includes failures due to lack of proper planning and anticipation. Finally, the third group includes failures caused by uncertainties that cannot be foreseen or planned for. Construction planners are advised to enhance their improvisational skills for better managing the third category of failures [20].

A previous research study has modeled improvisation in construction as a decision making process and explained its different stages [21]. Also, another study has defined improvisation in construction as a deliberate decision-making process that is usually used when: 1) speed is required to meet a deadline, 2) planned procedures fail to meet the requirements, 3) pre-planned strategies fail to manage a sudden problem, and 4) standardized procedures fail to catch up with daily ameliorations and progress [22]. Statistical analyses of this study have highlighted the frequent types of problems initiating improvisation and showed the effect of some personal and organizational characteristics on the outcomes of improvisation. The study concluded that "failure in execution" and "seeing opportunities to improve ready and sound tasks" are the most frequent triggers of improvisation in construction. However, the degree of novelty along with the level of complexity are distinguished as criteria to assess the significance of the associated problems initiating improvisation. Moreover, the outcome of individual improvisation is measured through two outcome indices which are: the level of emerging waste and the task completion status. On the other hand, task completion represents the extent to which planner has completed or solved the task under consideration via improvisation [22].

Results of the study showed that personal traits such as high experience, reacting well to time pressure, taking risks, and communicating with others have a significant impact on the level of emerging waste and the task completion status when employing improvisation. Furthermore, Organizations that empower employees, keep good records, and give levels of authority to experienced employees in the field have higher chances of sound improvisations [22].

While causes and some influencing factors of improvisation in construction have been examined in previous study, the overall behavior of several improvisers working together on a single construction project hasn't been analyzed yet. Indeed, different improvisational capabilities of planners who work in different trades within a construction project, as well as the level of the unexpected uncertainty associated with that project highly influence the total improvisational outcome. This paper employs agent-based modeling for explaining the improvisational mechanism of a group of construction individuals working on certain construction project.

2.3 Agent-based Modelling

Modelling is the act of projecting or imagining a certain occurrence, situation, or incident in individual's mind and then formulating it explicitly [23]. For explaining and representing these models, different approaches are used such as mathematical modelling that leads to analytical solutions for the perceived models. Mathematical modelling is mostly pertained to models or systems of which components and relationships can be expressed through mathematical equations [24]. However, most of the real-life occurrences and social systems are very complicated so they require computer simulation to be analyzed instead of the analytical approaches. Simulation is "the process of designing a dynamic model of an actual dynamic system for the purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of a system" [25]. Simulation is employed to mimic the operation of a real-life system by creating a simplified surrogate model representing that system. Systems are mainly simulated for measuring their performance, improving their operation, and/or testing the effect of a change or newly proposed practices [26].

Agent based modelling (ABM) is a recent approach used to model complex systems for the purpose of understanding, explaining, or analyzing how they do work. "Agents" are considered the main constituents of these systems; they are autonomous and interacting among each other and with their environment. Agents can be people, time, space, asset, a controlling element, or even a collection of elements. A set of static and/or dynamic attributes usually distinguishes them. Dynamic attributes are deemed important during simulation since they change according to the agents' interactions. Agents with different dynamic attributes behave differently, however; the overall behavior

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of the system cannot be predicted. Hence, simulation is required to conclude the inclusive emergent behavior of the existing system [27]. On the other hand, static attributes are fixed and unchangeable during simulation. They are usually used to distinguish between different agents.

Numerous researches have used agent-based modeling to mimic different systems in various fields of application. This approach of modeling has been employed to analyze organizational behaviors, transportation, economic, social, ecological, and robotic systems [28]. In the field of construction, agent-based modeling has grabbed the interest of several researchers since construction operations are inherently complex and non-linear [29]. Also, modelers have always emphasized on enhancing the construction safety, and thus simulated several scenarios for that purpose. For instance, Palaniappan et al. (2007) has modeled the causes of accidents on construction sites and the interactions between different project factors, aiming to enhance the safety performance on sites [30].

This study adopts agent-based modeling to analyze the improvisational practices of different groups of improvisers within a construction project. The simulation model aims to explain how the improvisational process occurs at the level of each planner, and it tends to examine how different combinations of improvisers and project-related factors shape the overall improvisational performance.

3. Methodology

A stepwise research methodology is designed to reach the study's objective. First, the authors have conducted a review on previous studies that addressed the topic of improvisation so that different types and characteristics of improvisational practices occurring in different organizational settings are examined. Then, a review on major contributions that aim to manage uncertainty as well as make use of improvisation in the construction field is performed. Also, a previous exploratory study addressing improvisational practices in construction is examined so that necessary data analysis and statistical outcomes are assessed and considered to be used further in this study. As a result, research gaps have been identified, and the contribution of this study in enhancing the practices of improvisation in construction has been set accordingly.

Second, agent-based modeling is used to mimic the behaviors of the improvisers. A conceptual model is developed while identifying the main environment, agents, influencing factors and parameters, as well as agents' behaviors and interactions. Building the components of the model is mainly based on the statistical findings of a previous research study as well as the available literature. Modeling the improvisation process could be considered as continuous loop that any construction individual could pass through. This loop starts with a problem causing improvisation and accordingly initiating the interaction between improvisers and the surrounding environment; this interaction is modeled using ABM. Then, agents improvise by passing through a well-defined process where behaviors and rules of interactions are set. Finally, the improvised solution is reached, and the level of success is determined accordingly; this is also modeled using ABM.

4. Agent-Based Modeling

4.1 Conceptual Framework

A conceptual framework is developed for elucidating the process of improvisation at the level of different individuals working together and interacting with one another within the same construction project. Also, this framework aims at depicting the impact of different improviser and project-related factors on the overall improvisational performance. The contribution of the developed conceptual model lies in providing a better understanding of the dynamics of the improvisational practices within a group of construction individuals as well as guiding construction professionals and planners to properly practice improvisation and make use of it under unexpected or unplanned conditions.

Similar to any organizational setting, improvisation in construction is usually observed in case of emergent, unplanned, and/or unexpected situations. Individuals who are in charge of executing, supervising, or planning for construction tasks are those who may face unexpected or unplanned work and eventually may end up improvising to solve the problem in hand. In other words, improvisation in construction occurs while individuals are trying to execute a certain task or endeavour. In this study, those individuals are called "planners" since they always have to plan even if they execute or supervise the work. Therefore, in this context, planners are potential improvisers. In case they decide to improvise, they will either succeed to solve the problem under consideration or not, depending on different influencing factors which are addressed in this framework.

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Different types of influencing factors significantly affect the way individuals improvise in construction and accordingly shape their improvisational outcomes. Construction planners usually improvise as they have to take decisions or actions swiftly in order to cope with an unplanned or unexpected event or situation. However, problems initiating improvisation are different in nature so that they require varying levels of improvisational efforts to be resolved. According to a previous research study, causes of improvisation are most likely to be: 1) missing pre-requisites, 2) inadequate definition of task, 3) opportunities to improve sound tasks, and/or 4) new circumstances during execution [22]. However, each kind of these problems is characterized by certain criteria that determine the extent of improvisational significance. These problem-related factors should be considered to analyze the process of improvisation rather than exploring different kinds of problems. The level of complexity and the degree of novelty are significant parameters to identify the required degree of improvisation and accordingly classify problems based on their improvisational requirements [22]. However, in the context of construction, there are other problem-related factors which can influence individual improvisational practices such as the number of trades on which the problems depend and the availability of the time duration to solve each problem. The following table provides definitions for problem-related factors, each of which can highly impact one's improvisational outcomes in construction.

Table 1- Problem-related factors

Problem-related factors	Definition
Level of complexity	Extent to which the goals associated with a given problem are undefined or unclear, and the degree to which the required methods to resolve the problem via improvisation are complex or hard.
Degree of novelty	Degree to which the problem in hands is totally new and novel
Trade interdependence	Number of trades on which the problem relies on
Time Availability	Available time to generate an action or decision in order to resolve the problem

On the other hand, improvisers have varying levels of personal criteria that highly shape their improvisational practices and accordingly influence their improvisational decisions or actions. For the same problem initiating improvisation, improvisers are expected to end up with different outcomes depending on their personal traits. Previous statistical analyses and hypotheses testing show that work experience, reacting well to time pressure, taking risk, and ability to communicate with others are significant influencing factors while studying improvisation in construction [22]. Also, the trade to which an improviser belong significantly shapes his/her improvisational process or mechanism. Another type of influencing factors is related to the project itself. The level of unforeseen uncertainty determines the extent to which improvisation is required in a certain project. In this framework, the level of uncertainty is modeled as a distribution of different types of problems initiating improvisation; these problems impose varying levels of improvisational efforts. Moreover, the distribution of improvisers among the trades as well as the way problems initiating improvisation are dispersed among the trades highly impact the overall improvisational performance in the project.

After identifying each of the problem, improviser, and project-related factors, construction planners will pass through the improvisation process and end up with a certain improvised decision or action. The success or the rightness of the improvised outcome is measured in this model through two outcome indices: 1) Level of emergent waste: how much waste is produced due to improvisation, and 2) Task completion status: how much the improvised decision or action has completed the task in hands or solved the problem. Therefore, improvisers might end up with one of the following outcomes: 1) Task completion without waste, 3) Task completion with waste, and 3) Task incompletion.

Note that improvisational experience is an essential parameter that affects the behaviors of improvisers with time. Initially, each improviser has a certain initial improvisational experience depending on his personal criteria. However, this initial experience won't be constant as improvisers are experiencing new improvisational instances as well as interacting with other improvisers within the same project. Therefore, the initial experience of improvisers will increase with time differently as they pass through different improvisational tasks. Moreover, it will also increase due to the interaction and learning effect among improvisers who belong to the same trade.

4.2 Results and Discussion

After developing a conceptual framework related to improvisation in construction, an agent-based model is built up through first identifying its component, then recognizing the linkages among these components. Fig.1 explains the rationale of the agent-based model. First, the environment is the construction project during which all construction planners belonging to different trades work and interact together. Second, problems initiating improvisation have different parameters such as level of complexity, degree of novelty, trade interdependence, and time availability. These problems are created as events in the environment so that improvisation is initiated at the level of different planner. As the problem reaches an improviser who is the main agent in the model, personal influencing factors shape the improvised outcome which is based on two outcome indices: 1) level of waste, and 2) task completion status.

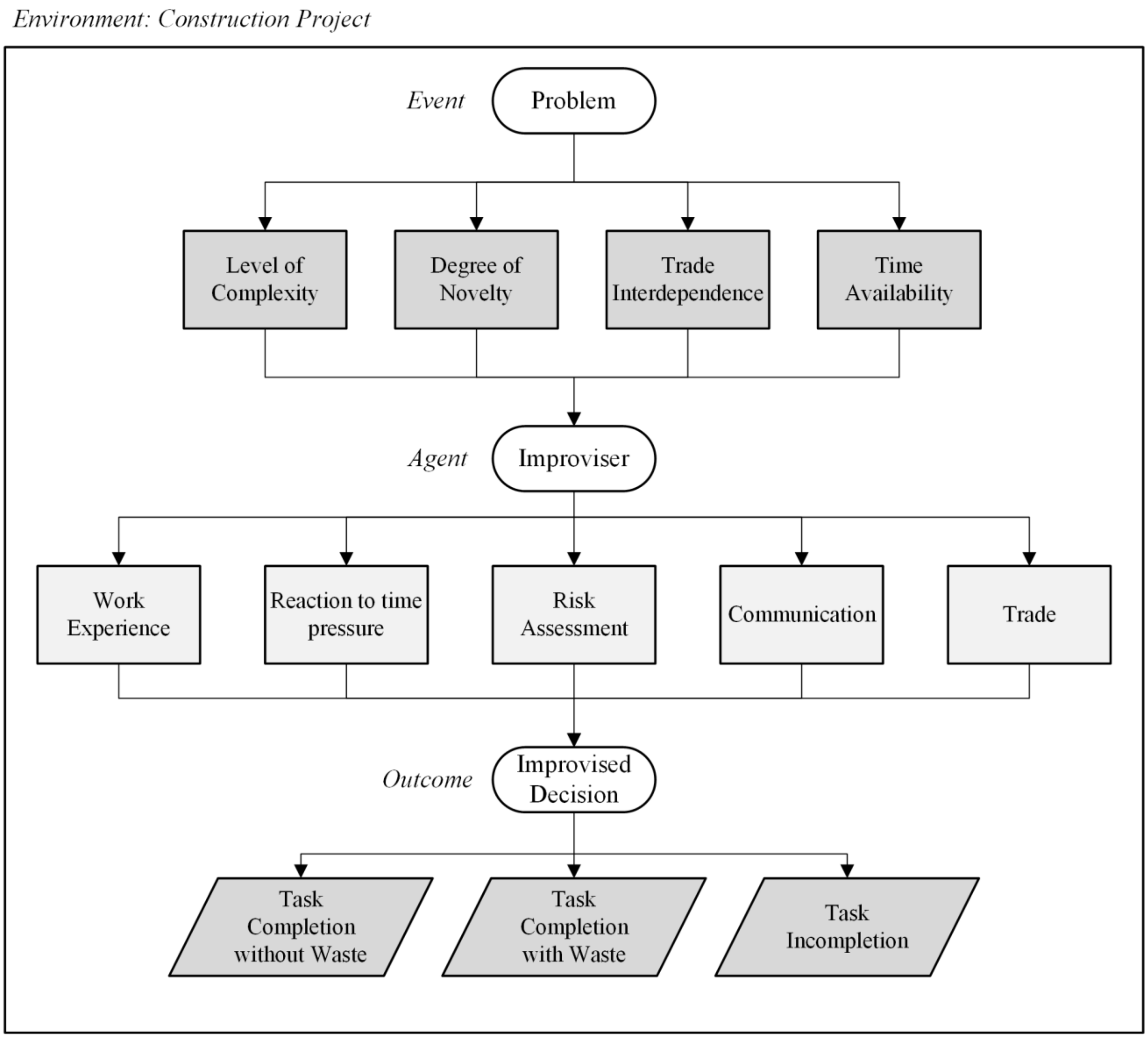

Fig.1. Agent-based Model

5. Conclusions and Future Work

Construction planning is deemed a crucial practice that aims to translate the project's goals into executable plans. However, one of the main issues that face planners and schedulers is the inability to stay on the pre-planned track during the construction phase. In some cases, such planning failures can be attributed to improper or even insufficient planning practices. However, failing to achieve the prearranged plans is often provoked by unforeseen or uncertain conditions, which are deemed companions to any construction project. Planners have tried hard to manage uncertainties in construction; however, unexpected uncertainties continue to exist during execution. Therefore, improvised solutions are usually required under such situations for maintaining full control on construction processes and reducing the potential induced losses and delays. Unfortunately, very few researches have tried to enhance the understanding of improvisation in construction, though it is an unavoidable practice in numerous construction operations.

Modeling the improvisation process could be seen as a continuous loop that any construction planner could pass through. As a rule, the loop starts with a problem from a given environment and the corresponding interaction that would occur due to this problem between the agent and the environment (modeled using Agent Based Modeling), followed with a solution generation process to reach the improvised decision, during the solution generation process different interactions would occur between different agents (modeled using Agent Based Modeling), finally an attempt to implement the solution by improviser is done and the level of success is determined accordingly (modeled using Agent Based Modeling).

Improvisation is a topic that is being addressed by several studies; some studies define it while others describe it. This paper sets the premise for modeling the improvisation process and thus offers the ability to measure the performance of improvisers as well as the impact of improvisation on the planning and construction process. Therefore, proper proactive actions could be taken to optimize the improvisation process in construction. Besides, defining and modeling different attributes which construction planners would provide the capability of better understanding the mechanism that each improviser can follow.

To achieve the above-mentioned goals, further research work is required to perform the following: 1) Quantifying the defined attributes and provide a weighing factor for each one, and 2) Gathering data corresponding to different cases from the construction industry in which failure occur and use them as input, 3) Running the simulation model for several cases, and 4) Measuring the influence of variation of personal and project-related factors on the improvised outcomes.

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Analyzing the Critical Risk Factors in Oil and Gas Pipelines Projects Regarding the Perceptions of the Stakeholders

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Abstract

Oil and Gas Pipeline (OGP) projects face a wide range of Risk Factors (RFs) at the design, construction and operational stages of the project particularly because of Third Party Disturbance (TPD) in the insecure environments. The lack of risk information and the root causes of pipelines' failures are hindering the efforts of managing these risks. Therefore, this paper aims to analyze the existing risk factors and recommend an effective Risk Mitigation Methods (RMMs) based on a holistic approach from the prospect of stakeholders' interest. An investigation was carried out to identify the critical RFs and existing RMMs in different circumstances to overcome the problem of the historical records about the RFs and RMMs. The findings of the literature review were used to design a questionnaire survey to analyze RFs and evaluate the "usability and effectiveness" of the RMMs. The RFs were ranked by using Risk Index (RI) method based on the probability and severity levels of each RF. The survey results revealed that sabotage and terrorism as part of TPD, corruption and insecure areas are the most critical RFs, whereas, anti-corrosion efforts, underground pipelines and technologically advanced risk monitoring systems are the most effective RMMs. These ranking are vary based on the occupation of the stakeholder in OGPs; like the planners and the researchers said corruption is the most critical RF, and the researchers said that the advance risk monitoring systems are the most effective RMM.

Keywords: Oil and gas pipelines (OGPs), risk analysis, Stakeholders' perceptions, Risk Mitigation Methods (RMMs)

1. Introduction

Oil and Gas Pipelines (OGPs) projects must be planned, designed, installed and operated in ways that comply with the safety requirements. However, several risks are hindering the safety of these projects such as external sabotage, corrosion [1], design and construction defects, natural hazards, operational errors and more risks [2-4]. Mitigating OGPs' RFs is a valuable knowledge because it minimizes the economic losses from disturbing the business of oil export; as well as, it ensures the safety of the projects' stuff and the people that live near the pipelines.

The efforts of mitigating OGPs RFs are significantly require verified historical records about the pipelines' accidents and failure reasons [5,6]. Moreover, the probability of RFs must be accurately analyzed and ranked because dealing with each RF as the most severe risk results resources wistful. However, the existing risk analysis methods are not accurate enough to analyze the external sabotage of the pipelines when there is no database "historical records" about such risk [7-9]. Additionally, an accurate evaluation of the Risk Mitigation Methods (RMMs) in term of their degrees of "usability and effectiveness" degrees of mitigating the RFs helps the decision makers while they are considering their plans to mitigate OGPs' RFs. Accordingly, the inaccurate analyses of OGPs' RFs and inaccurate evaluation of the RMMs are hindering any efforts of risk mitigation in these projects. Particularly, in the troubled and developing

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countries because these highlighted problems are crucial and associate with OGP projects in these countries. Hence, there is a vital need to help the stakeholders to improve the safety for these projects by providing the required data for OGPs risk management such as the "probability and severity" levels of the RFs and the "usability and effectiveness" of the RMMs.

The aim of this paper is to analyze the RFs and evaluate the RMMs in OGPs projects more holistically and effectively base on qualitative documents analysis and a questionnaire survey. Moreover, the up-to-date data about the RFs and RMMs can help the stakeholders to improve the safety of GOPs continuously.

Iraq is selected as the case study in this paper because its oil reserves is the fifth-largest oil reserves in the world [10]. As well as, it are estimated that Iraq's gas reserves are amongst 10^{th} to 13^{th} largest reserves globally, in addition to vast potential reserves for further discoveries [11]. At the present time, a vast range of RFs threatens OGPs project in Iraq and the inadequacy of mitigating the RFs hinders the business of oil export which is in high demand after 2003.

Moving forward in this paper, section 2 consists a review about identifying pipelines' RFs and RMMs. Section 3 explains the research methodology. The results of analyzing the RFS and evaluating RMMs are interpreted in section 4. Section 5 discusses this paper' findings. Finally, section 6 shows the conclusions.

2. Identifying the Risk Factors (RFs) and Risk Mitigation Methods (RMMs) in OGPs Projects

Qualitative documents analysis were carried out to identify the RFs in OGPs projects in different circumstances, especially in the insecure countries. Thirty RFs were identified based on the findings of the literature review that are shown in Table 1.

Table 1. The identified RFs in OGPs projects from the literature review.

RFs	Author
Thieves	12
Publics' legal and moral awareness about OGPs projects	7
Peoples' education and poverty levels in OGPs areas	12
Leakage of sensitive information	13
Threats to staff	14
Sabotage and Terrorism	12
Accessibility of pipelines	15
Conflict over land ownership	16
Insecure areas	15
Vehicle accidents	7
Animal accidents	17
Geological RFs	18
Lack of regular inspections and maintenance of OGPs	12
The opportunity to sabotage exposed pipelines "aboveground pipelines"	14
Lack of compliance with the safety regulations	18
Weather conditions and natural disasters	12
Inadequate risk management approaches	12
Non-availability of warning signs	12
Weak ability to identify and monitor the RFs	12
Corrosion and lack of anti-corrosive action	12
Shortage of modern IT services	12
Design, construction and material defects	18
Hacker attacks on the operating or control systems	15
Operational errors	12
Corruption	12
Few researchers about this problem	12
Lawlessness	7
Lack of proper training schemes	12
No proper attention from the stakeholders	12
Lack of historical records and data about RFs	12

These wide investigations helped to overcome the problem of data scarcity about the RFs in OGPs projects in Iraq. Accordingly, a number of RMMs was suggested to mitigate RFs like anti-corrosion and cathodic protection; laying the pipelines underground rather than aboveground; modern equipment to monitor the RFs; proper inspection and maintenance; proper training for the stuff about mitigation the RFs in their projects; avoid insecure areas; anti-terrorism planning and design; avoid the registered RFs; protective barriers; government-public cooperation; and warning signs near the pipelines and marker tape above the pipeline.

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Table 1 cannot give accurate information about the "probability and severity" of the RFs. As well as, the suggested RMMs need to be evaluated regarding their degrees of "usability and effectiveness" to mitigate the RFs in OGPs projects. Therefore, the filed investigations were required to analyze the contents of OGPs' safety in Iraq by distributing a questionnaire survey.

3. Methodology

An industry-wide questionnaire survey was designed based on the findings of the literature review (see Table 1) in order to analyze the RFs based on the perceptions of the stakeholders in OGPs in Iraq. In this survey, the RMMs will be evaluated too. The respondents were promised that the data will be anonymity analyzed.

The first question was asked about the occupation of the respondents in OGPs projects. The survey had two questions to analyze the RFs as follows. The first question was addressed to analyze the probability of occurrence of the 30 RFs on a five-point rating Likert scales which is "rare, unlikely, possible, likely and almost certain". The second question was analyze to evaluate the severity of the RFs on a scale "negligible, minor, moderate, major and catastrophic". Similarly, the survey had two questions to evaluate the RMMs as follows. The first question was asked about evaluating the usability of the RMMs on a scale "rare, unlikely, possible, likely and almost certain". The second question was about evaluating the effectiveness of RMMs on a scale "ineffective, slightly effective, moderately effective, very effective, and extremely effective".

The descriptive statistical analysis in Statistical Package for the Social Sciences (SPSS) software was used to determine the values of Risk Probability (RP) and Risk Severity (RS) for each RF by calculating the mean of the five point Likert scales. The degree of impact for each RF was found by using Risk Index (RI) method as explained in Eq. (1) [19]. The RFs were ranked regarding their RI values. In the same way, the usability and the effectiveness of the RMMs were found.

$$RI = (RP \times RS)/5 \quad (1)$$

4. Results

The survey was distributed online and it was targeting the owners, clients, researchers, consultants, planners, designers, and construction, operators, maintenance workers in Iraq's OGPs projects. 198 respondents from stakeholders have answered the survey's questions as shown in

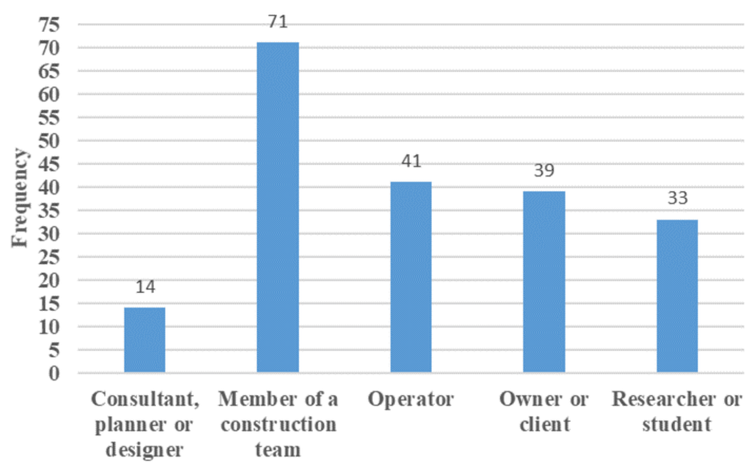

Fig. 1: Participants' demographic information.

Fig 1. As shown in Fig. 1, the majority of the participants were members of construction teams, followed by the operators, owners or clients, researchers or students and the less majority was for the consultants, planners and designers.

The Cronbach's alpha correlation coefficient factor was calculated to measure the reliability level of the survey [20,21]. Commonly 0.7 indicates a minimum level of reliability [22]. Table 2 shows the Cronbach's alpha coefficient factor case processing summary. The reliability test is not applicable for question 1 because it was asking about the participants' occupation in OGPs projects.

Table 2. Cronbach's alpha coefficient factor case processing summary for the survey overall and by participants' occupation.

Case Processing Summary	Valid %	Items	α
All the questionnaire's questions	100	95	0.910
The question about RP (survey overall)	100	30	0.919
The question about RS (survey overall)	100	30	0.863
The question about the usability of RMMs (survey overall)	100	12	0.867
The question about the effectiveness of RMMs (survey overall)	100	12	0.792
a consultant, planner or designer	100.0	95	0.863
a member of a construction team	100.0	95	0.892
an operator	100.0	95	0.927
an owner or client	100.0	95	0.917
a researcher or student	100.0	95	0.899

Based on the occupations of the stakeholder in OGPs projects in Iraq, Table 3, Table 4 and Table 5 show the results of calculating the RP, RS and RI of each RF respectively. Table 6 shows the ranking of the RFs based on their values of RI. The usability and effectiveness of the RMMs are shown in Table 7 and Table 8 respectively. Please note in these tables means the whole participants; (I) means the consultants, planners and designers; (II) means the construction workers; (III) means the operation and maintenance workers; (IV) means the owner and client; and (V) means the researchers.

Table 3. The probability of the risk factors by participants' occupation.

RFs	(Risk Probability) RP					
	Total	I	II	III	IV	V
Terrorism & sabotage	3.995	3.357	3.958	4.195	4.000	4.091
Corruption	3.980	4.000	3.986	3.878	3.846	4.242
Insecure areas	3.717	3.286	3.634	3.805	3.769	3.909
Low public legal & moral awareness	3.712	4.000	3.761	3.561	3.513	3.909
Thieves	3.692	3.214	3.845	3.659	3.564	3.758
Corrosion & lack protection against it	3.687	3.429	3.648	3.390	3.795	4.121
Improper safety regulations	3.687	3.643	3.662	3.561	3.872	3.697
Exposed pipelines	3.667	3.429	3.437	3.854	3.897	3.758
Shortage of the IT services & modern equipment	3.667	3.643	3.592	3.585	3.615	4.000
Improper inspection & maintenance	3.657	3.571	3.606	3.537	3.769	3.818
Lack of proper training	3.646	3.571	3.761	3.439	3.462	3.909
Weak ability to identify & monitor the threats	3.631	3.571	3.577	3.561	3.692	3.788
The pipeline is easy to access	3.631	3.571	3.563	3.732	3.538	3.788
Limited warning signs	3.626	3.429	3.648	3.341	3.974	3.606
Little researches on this topic	3.621	3.429	3.789	3.366	3.359	3.970
Lawlessness	3.606	3.786	3.676	3.268	3.795	3.576
Lack of risk registration	3.566	3.214	3.606	3.390	3.615	3.788
Stakeholders are not paying proper attention	3.530	3.286	3.676	3.439	3.462	3.515
Conflicts over land ownership	3.495	3.571	3.451	3.659	3.667	3.152
Public's poverty & education level	3.449	3.357	3.521	3.439	3.256	3.576
Design, construction & material defects	3.333	2.429	3.254	3.293	3.385	3.879
Threats to staff	3.323	2.714	3.394	3.268	3.410	3.394
Inadequate risk management	3.227	2.929	3.183	2.976	3.436	3.515
Operational errors	3.101	2.857	3.042	2.878	3.205	3.485
Leakage of sensitive information	2.980	2.643	3.070	2.707	2.949	3.303
Geological risks	2.747	2.714	2.662	2.537	2.795	3.152
Natural disasters & weather conditions	2.652	2.429	2.606	2.537	2.692	2.939
Vehicles accidents	2.465	2.357	2.380	2.293	2.333	3.061
Hacker attacks on the operating or control system	2.237	1.929	2.268	2.024	2.179	2.636
Animals accidents	1.894	1.929	1.986	1.561	1.821	2.182

Table 4: The severity of the risk factors by participants' occupation.

RFs	(Risk Severity) RS					
	Total	I	II	III	IV	V
Terrorism & sabotage	4.490	3.571	3.732	3.829	3.718	3.939
Corruption	4.323	3.500	3.958	3.57	3.692	3.636
Lawlessness	4.192	3.286	3.732	3.512	3.769	3.939
Insecure areas	4.106	3.286	3.634	3.659	4.000	3.606
Thieves	4.081	3.000	3.662	3.585	3.846	3.818
Corrosion & lack protection against it	3.990	3.357	3.676	3.683	3.641	3.697
Stakeholders are not paying proper attention	3.960	3.143	3.577	3.829	3.692	3.727
Improper safety regulations	3.949	3.214	3.592	3.488	3.872	3.667
Improper inspection & maintenance	3.924	3.357	3.746	3.610	3.641	3.394
Weak ability to identify & monitor the threats	3.899	3.000	3.690	3.488	3.487	3.758
Low public legal & moral awareness	3.859	3.357	3.535	3.244	3.590	3.727
Design, construction & material defects	3.848	3.571	3.549	3.390	3.179	3.333
Lack of proper training	3.773	3.500	3.408	3.098	3.410	3.697
Threats to staff	3.732	2.857	3.014	3.293	3.128	3.606
Lack of risk registration	3.697	2.857	3.042	2.854	3.077	3.455
Exposed pipelines	3.682	2.500	3.042	2.951	3.000	3.000
Limited warning signs	3.662	2.143	2.676	2.780	2.846	2.788
Shortage of the IT services & modern equipment	3.652	1.714	2.155	1.951	2.000	1.970
The pipeline is easy to access	3.646	3.571	3.732	3.829	3.718	3.939
Operational errors	3.611	3.500	3.958	3.537	3.692	3.636
Conflicts over land ownership	3.611	3.286	3.732	3.512	3.769	3.939
Little researches on this topic	3.571	3.286	3.634	3.659	4.000	3.606
Leakage of sensitive information	3.505	3.000	3.662	3.585	3.846	3.818
Public’s poverty & education level	3.409	3.357	3.676	3.683	3.641	3.697
Inadequate risk management	3.399	3.143	3.577	3.829	3.692	3.727
Geological risks	3.182	3.214	3.592	3.488	3.872	3.667
Natural disasters & weather conditions	3.066	3.357	3.746	3.610	3.641	3.394
Hacker attacks on the operating or control system	2.970	3.000	3.690	3.488	3.487	3.758
Vehicles accidents	2.712	3.357	3.535	3.244	3.590	3.727
Animals accidents	2.020	3.571	3.549	3.390	3.179	3.333

Table 5. The index of the risk factors by participants' occupation.

RFs	(Risk Index) RI					
	Total	I	II	III	IV	V
Terrorism & sabotage	3.587*	3.021	3.579	3.909	3.405	3.669
Corruption	3.441	3.314	3.537	3.254	3.314	3.677
Insecure areas	3.053	2.722	2.928	3.267	3.035	3.222
Lawlessness	3.023	2.812	3.210	2.583	3.211	3.056
Thieves	3.013	2.388	3.206	2.998	2.906	3.029
Corrosion & lack protection against it	2.942	2.498	2.918	2.696	3.172	3.222
Improper safety regulations	2.912	2.810	2.899	2.797	2.958	3.070
Improper inspection & maintenance	2.870	2.755	2.742	2.829	3.015	3.078
Publics’ legal and moral awareness	2.865	3.086	2.934	2.588	2.738	3.127
Weak ability to identify & monitor the threats	2.832	2.551	2.802	2.831	2.878	2.961
Stakeholders are not paying proper attention	2.796	2.629	2.972	2.583	2.716	2.855
Lack of proper training	2.751	2.551	2.807	2.634	2.574	3.080
Exposed pipelines	2.700	2.253	2.498	2.820	3.118	2.710
Shortage of the IT services & modern equipment	2.678	2.446	2.641	2.641	2.633	2.958
Limited warning signs	2.656	2.057	2.672	2.396	3.057	2.754
The pipeline is easy to access	2.648	2.245	2.550	2.858	2.613	2.824
Lack of risk registration	2.636	2.112	2.692	2.381	2.725	2.984
Little researches on this topic	2.586	2.057	2.796	2.348	2.343	2.983
Design, construction & material defects	2.566	1.839	2.410	2.538	2.760	3.033
Conflicts over land ownership	2.524	2.398	2.586	2.641	2.670	2.139
Threats to staff	2.481	1.900	2.687	2.312	2.518	2.468
The education and poverty levels in OGPs areas	2.352	2.398	2.500	2.332	2.071	2.384
Operational errors	2.240	1.837	2.185	2.008	2.482	2.556
Inadequate risk management	2.194	2.050	2.170	1.843	2.343	2.599
Leakage of sensitive information	2.089	1.774	2.171	1.756	2.117	2.462
Geological risks	1.748	1.551	1.605	1.670	1.749	2.273
Natural disasters & weather conditions	1.626	1.388	1.585	1.448	1.657	2.031
Vehicles accidents	1.337	1.010	1.274	1.275	1.328	1.707
Hacker attacks on the operating or control system	1.329	0.964	1.380	1.195	1.308	1.582
Animals accidents	0.765	0.661	0.856	0.609	0.728	0.860

*For example: RI for Terrorism & sabotage = 3.995 (RP from Table 3) × 4.490 (RS from Table 4) = 3.587

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Table 6: The ranking of the RFs by participants' occupation.

RFs	Ranking the RFs					
	Total	I	II	III	IV	V
Terrorism & sabotage	1	3	1	1	1	2
Corruption	2	1	2	3	2	1
Insecure areas	3	7	7	2	7	4
Lawlessness	4	4	3	16	3	9
Thieves	5	15	4	4	10	11
Corrosion & lack protection against it	6	11	8	10	4	3
Improper safety regulations	7	5	9	9	9	8
Improper inspection & maintenance	8	6	13	7	8	7
Publics' legal and moral awareness	9	2	6	14	13	5
Weak ability to identify & monitor the threats	10	10	11	6	11	14
Stakeholders are not paying proper attention	11	8	5	15	15	16
Lack of proper training	12	9	10	13	19	6
Exposed pipelines	13	16	21	8	5	19
Shortage of the IT services & modern equipment	14	12	17	12	17	15
Limited warning signs	15	20	16	18	6	18
The pipeline is easy to access	16	17	19	5	18	17
Lack of risk registration	17	18	14	19	14	12
Little researches on this topic	18	19	12	20	23	13
Design, construction & material defects	19	23	22	17	12	10
Conflicts over land ownership	20	14	18	11	16	26
Threats to staff	21	22	15	22	20	22
The education and poverty levels in OGPs areas	22	13	20	21	25	24
Operational errors	23	24	23	23	21	21
Inadequate risk management	24	21	25	24	22	20
Leakage of sensitive information	25	25	24	25	24	23
Geological risks	26	26	26	26	26	25
Natural disasters & weather conditions	27	27	27	27	27	27
Vehicles accidents	28	28	29	28	28	28
Hacker attacks on the operating or control system	29	29	28	29	29	29
Animals accidents	30	30	30	30	30	30

Table 7. The usability degree of each RMM by participants' occupation.

RMMs	Usability					
	Total	I	II	III	IV	V
Avoid "Insecure-Zones	3.652	2.929	3.789	3.829	3.385	3.758
Anti-terrorism design	3.475	2.643	3.676	3.268	3.564	3.545
Avoid the registered risks and threats	3.616	3.357	3.662	3.634	3.513	3.727
Proper training	3.768	3.643	3.634	3.854	3.769	4.000
Move to an underground pipeline	4.051	3.857	4.085	4.390	3.846	3.879
Anti-corrosion such as isolation and cathodic protection	4.247	4.000	4.282	4.512	4.103	4.121
Protective barriers and perimeter fencing	3.783	3.214	3.732	3.878	3.872	3.909
Warning signs and marker tape above the pipeline	3.727	3.143	3.732	3.683	3.846	3.879
Foot and vehicles patrols	3.606	3.143	3.648	3.683	3.590	3.636
High technology and professional remote monitoring	3.480	2.643	3.606	3.415	3.359	3.788
Government-public cooperation	3.278	3.000	3.183	3.463	3.205	3.455
Proper inspection, tests and maintenance	3.677	3.429	3.549	3.805	3.769	3.788

Table 8. The effectiveness degree of each RMM by participants' occupation.

RMMs	Effectiveness					
	Total	I	II	III	IV	V
Anti-corrosion such as isolation & cathodic protection	4.232	3.857	4.113	4.415	4.513	4.091
Move to an underground pipeline	4.066	3.929	4.000	4.220	4.333	3.758
High technology & professional remote monitoring	3.995	3.643	4.070	3.878	4.000	4.121
Proper inspection, tests & maintenance	3.828	3.429	3.887	3.829	3.872	3.818
Proper training	3.793	3.857	3.662	3.780	3.897	3.939
Avoid "Hot-Zones	3.778	3.214	4.014	3.659	3.744	3.697
Anti-terrorism design	3.778	3.143	3.986	3.341	4.179	3.667
Avoid the registered risks & threats	3.773	3.500	3.817	3.683	4.000	3.636
Protective barriers & perimeter fencing	3.682	3.214	3.577	3.756	3.872	3.788
Warning signs & marker tape above the pipeline	3.571	2.929	3.577	3.439	3.923	3.576
Government-public cooperation	3.545	3.214	3.563	3.561	3.564	3.606
Foot & vehicles patrols	3.530	3.429	3.563	3.634	3.615	3.273

5. Discussion

By using the RI to rank the RFs, the overall results of the survey show that the terrorism and sabotage, corruption, insecure areas, lawlessness and thefts are the most critical RFs in OGPs projects in Iraq. Nevertheless, the ranking of the RFs is quite varied deepening on the occupations of the stakeholders. Regarding the planners, consultants and designers perceptions corruption, low public legal and moral awareness, sabotage actions, lawlessness and improper safety regulations are the top five RFs that influence the pipeline projects. The stakeholders who are working in the construction filed have ranked the top five of RFs as follows. Terrorism and sabotage actions, corruption, lawlessness, corrosion and lack protection against it, thefts and the stakeholders are not paying proper attention. The operators have come with different ranking as follows. Terrorism and sabotage actions, insecure areas, corruption, thefts, and the pipelines are easy to access. The projects' owners and clients have said that the terrorism and sabotage actions, corruption, lawlessness, corrosion and lack protection against it, and the exposed "aboveground" pipelines are the top five RFs. The participants from the academic field indicated that corruption, terrorism and sabotage actions, corrosion and lack protection against it, insecure areas and low public legal and moral awareness the most critical RFs.

Regarding evaluating the RMMs by their degree of usability, the overall results of the survey indicate anti-corrosion such as isolation and cathodic protection, move to an underground pipeline and protective barriers and perimeter fencing are the RMMs with the higher chance of usability in OGP projects in Iraq. The planners, consultants and designers have another point of view, which is anti-corrosion such as isolation and cathodic protection, move to an underground pipeline, and proper training are the mitigation methods with the higher rate of usability. Anti-corrosion such as isolation and cathodic protection, move to an underground pipeline and avoid "Insecure-Zones" are the more useable methods as construction said. The operators came with a different observation that is like this anti-corrosion such as isolation and cathodic protection, move to an underground pipeline and protective barriers and perimeter fencing are the most useable methods. Which slightly different for the owners and clients observations that are as follows: the methods of the higher rate of usability are anti-corrosion such as isolation and cathodic protection, protective barriers and perimeter fencing and move to an underground pipeline. The researchers said that the anti-corrosion such as isolation and cathodic protection, proper training and protective barriers and perimeter fencing are the most usable risk mitigation methods.

The result of evaluating the effectiveness of the RMMs are anti-corrosion such as isolation and cathodic protection, move to an underground pipeline and high technology and professional remote monitoring are the most effective RMMs. However, move to an underground pipeline, anti-corrosion such as isolation and cathodic protection and proper training are the most effective RMMs as the consultants, planners and designers said. Which is different from the observation of the construction teams that are as follows. Anti-corrosion such as isolation and cathodic protection, high technology and professional remote monitoring and avoid "Insecure-Zones are the most effective RMMs. The opinion of the operators is like that anti-corrosion such as isolation and cathodic protection, move to an underground pipeline and high technology and professional remote monitoring are the most effective RMMs. Which is different from the opinions of the owners and clients as they said anti-corrosion such as isolation and cathodic protection, move to an underground pipeline and anti-terrorism design are the most effective RMMs. The researchers think like that high technology and professional remote monitoring, anti-corrosion such as isolation and cathodic protection and proper training are the most effective RMMs.

The survey results were found to be reliable as all Cronbach's alpha coefficient factor values are above 0.7, as explained in Table 2. Collecting the required information from various and trusted sources such as research articles and stakeholders provides real information for OGPs risk management. However, it depends on the availability of such documents and the willingness of the stakeholders to cooperate with the authors. Analyzing the RFs and evaluating the RMMs based on the perceptions of the stakeholders could reduce the time and the cost of the investigations and increase the stakeholders' awareness about their responsibilities regarding OGPs risk management. As well as, it helps to analyze OGPs RFs more realistically and to identify the positive and negative recommendations about RMMs in a way that ensure the continuity of pipeline security. Because the perceptions of the stakeholders are based on real experience about OGPs issues. Furthermore, correct sampling and representing the whole stakeholders' categories enhances the results of RFs analysis and RMMs evaluation.

6. Conclusion

There is a need for an accurate analysis of OGPs RFs because the external RFs have not been accurately analyzed yet. The overall results of the survey showed that the external risk factors like terrorism and sabotage, corruption, insecure areas, lawlessness and thieves were found the most critical risks in OOPs projects in Iraq. Avoid "Insecure-Zones, anti-terrorism design and avoid the registered risks and threats were found as the most usable risk mitigation methods. Meanwhile, anti-corrosion such as isolation & cathodic protection, move to an underground pipeline and high technology & professional remote monitoring were the most effective risk mitigation methods. While, regarding their occupations in OGPs, the stakeholders in OGPs have different perceptions about this ranking.

This paper provided verified information about risk factor and risk mitigation methods such identifying the risk factors, analyzing the factors' "probability and severity" and evaluating the "usability and the effectiveness" of the risk mitigation methods. Such information could the help organizations and countries that just began to mitigate OGPs risk factors more effectively and to provide useful recommendations for their actions and plans about OGPs risk management in the insecure countries such as Iraq.

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Appraising the Utility of Internet-Mediated Communication for Qualitative Data Collection in Built Environment Research

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Abstract

Qualitative researchers within the built environment (BE) research community are confronted with data collection challenges. Such challenges have been attributed to the nature of the construction industry which has been described as fraught with high worker turnover rates and tight schedule of project stakeholders. These features diminish a researcher's chances of engaging in successful and in-expensive data collection exercises. A cursory look at studies reveals the fixation of qualitative researchers within the BE discipline on conventional qualitative data collection techniques whilst neglecting internet-mediated communication (IMC) techniques. This study contributes towards elucidating the usefulness of IMC techniques as a data collection approach for qualitative researchers in the built environment domain. An asynchronous online discussion forum (AODF) case study is deployed as an exemplar in this study. Advantages of ADOF highlighted in the reviewed include: its cost-effectiveness, automatic transcription, ability to reach discussants across various geographical contexts, etc. Also, its shortcomings, like the challenge of sustaining thread discussions were observed. In furtherance to this, it was discovered that the attainment of theoretical saturation with the AODF posed a challenge. It is expected that this study will contribute to the emerging discourse on the utility of such IMC techniques in the built environment domain, particularly with the evolving industry 4.0 agenda.

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Keywords: Asynchronous online discussion forums; Built environment; Internet-mediated Communication; Qualitative research

1. Introduction

Data collection continues to pose a challenge to researchers, especially qualitative researchers within the built environment (BE) research domain. Qualitative data has been eulogized for making significant contributions towards theory development as it facilitates the unbridled elicitation of the worldviews of prospective participants in research projects [6]. However, the process of collecting qualitative data can best be described as labourious. This is due to the presence of several challenges attributed to the temporary and fragmented nature of the industry, tight schedules experienced by project stakeholders within the construction environment, the geographically dispersed locations which the researcher must cover to reach a wider sample of potential interviewees or discussants [22]. This has been the lot of the qualitative researcher as issues of limited funding and timescales pose as significant obstacles to the seamless achievement of the research objective.

Yet, the conventional means of eliciting data through face-to-face interviews, focus group discussion as well as observation have remained predominant among qualitative researchers. As its central proposition, this study postulates that these approaches have negated the level of productivity experienced during data collection processes in qualitative research projects. It opines that overt dependence on the internet-mediated communication (IMC) techniques will lead to an increase in productivity levels without compromising on the quality and credibility of the findings emanating from the research project.

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The advent of the internet in the 80's and 90's has led to a transformational curve across various facets of contemporary living [25, 27]. As such, significant improvements leading to efficiency and increased productivity have leveraged on this innovation. The educational sector remains a major beneficiary of the internet as the medium has been applied towards the development of pedagogical platforms for sharing knowledge between persons situated across geographically dispersed locations on a real-time, online basis without any time and distance barriers [21]. This has proven to be a cost-effective approach to pedagogy as many academic institutions have resorted to hosting their programmes through internet-/computer-mediated platforms and improving staff and student productivity [1]. As such, significant investments are continually being made by academic institutions at different levels to foster an internet-dependent culture across the entire gamut of their institutional activities. Although the use of the IMC platforms appears to have been extensively deployed in improving teaching and learning processes in these institutions, it appears that it is yet, a new concept to qualitative researchers within the BE research space [16]. Partly, the apathy to the optimal utilization of IMC techniques in engendering effective and efficient data collection processes have resulted from the uncertainty surrounding its adoption and deployment [25]. Such uncertainty stems from issues like the acceptability of the findings resulting from the study, security of information shared over such platforms and willingness of participants to share such information across such platforms, the level of access to internet connectivity as well as ability to engage with the internet in certain contexts by certain categories of participants which may affect participation levels, etc. [16, 5].

But, [27] Turney and Pocknee (2005) admit to the vast opportunity presented by the internet and internet-enabled platforms in supporting the researcher's ability to document data in a text format, providing conducive environments for participants to voice their opinions pertaining to a phenomenon. In furtherance to this, a review of existing literature reveals a paucity of literature detailing a procedural approach to the deployment of these IMC platforms by qualitative researchers, both within and outside the BE domain during data elicitation processes [11]. Perhaps, the abundance of such articles as is the case with the pedagogical facets will engender increased utilization of IMC platforms among researchers. This is a gap which this study seeks to bridge. [16] Im and Chee (2006) admit this when they bemoan the low level of awareness in the research community regarding the practical issues associated with the use of the online platforms for data elicitation. Accordingly, this study will provide an insight into the utility of such IMC platforms in the collection of qualitative data within the BE context, relying on an asynchronous online discussion forum (AODF) exemplar. Furthermore, it will highlight the advantages as well as shortcomings of the AODF experienced by the researcher during the study being presented and the steps taken to surmount these challenges.

To achieve its objective, this study will be structured thus: a review of relevant literature on the nature of online discussion forums; a reflection on the similarities between AODFs and conventional focus group discussion platforms; the nature of the construction industry and BE research; an exposé on the study within which the AODF was applied to collect data; a reflection on the drivers, merits, challenges and ethical considerations experienced during the deployment of the AODF in the study, and; a conclusion.

2. Literature review

2.1. Online discussion forums

The advent of the internet appears to have brought in its wake a paradigmatic shift in the way certain processes were executed [5, 7, 2]. They admit that the internet is a veritable platform for carrying out unbiased research and offers the researcher with an opportunity of experiencing a plethora of nuanced instances which may not have been possible with the conventional modes of data collection. Also, [25] observe the burgeoning rise of the internet usage in the research community despite little reportage. They identify the utility of the internet in carrying out literature reviews, and the compilation of bibliographic databases among other aspects. The rise in the use of IMC platforms to facilitate borderless dissemination of knowledge as well as information sharing across multiple platforms evolved from this era. Online discussion forums are IMC platforms which have been extensively deployed towards knowledge creation/development and dissemination among different individuals across different locations. In elucidating the usefulness of online discussion forums, Gao et al (2013) [11] catalogue a variety of uses to which such platforms can be put to. Examples of such uses include the development of online communities, enabling unbridled information and knowledge exchange, provision of a platform for collaborative problem-solving and critical and reflexive thinking.

Whereas online discussion forums have a long history of being applied in the pedagogical undertakings in academic institutions, its introduction to the research community can be described as relatively nascent [5, 17, 27, 24]. However, they opine that its adoption within the research context has availed researchers with an opportunity to gain access to previously hard to reach groups. This was buttressed in a recent study [19] wherein an online discussion forum was used gathering qualitative data from young people who have experienced breakups in romantic relationships and in another study, wherein online discussion forums where applied in understudying the perception of the youth on the burgeoning housing issues in their locality by [20]. Maestre et al. (2018) [18] highlight the salient nature of online discussion forums in researching into stigmatized groups. Whilst it should be acknowledged that the participants in a multiplicity of BE research projects cannot be assigned the toga of a 'hard to reach' sample, it is often difficult to recruit probable participants. This difficulty is because of the different factors which have been mentioned previously in the preceding section. The presence of such challenges which are peculiar to BE context accentuates the need for the adoption and utilization of IMC platforms to gather data in an effective and efficient manner. Online discussion forums are classified according to two distinct categories, namely: synchronized and asynchronized online discussion forums [25]. Whereas the synchronized communication takes place online, real-time and instantaneously, the latter avails participants with an opportunity to provide answers at their convenience. Examples of the former include online chat-rooms and online interviewing platforms such as Skype and other types of voice over internet protocol (VOIP) platforms whereas online discussion forums/ boards can be classified as being asynchronous discussion platforms. Also, the asynchronous category allows for participants to join in on any discussion at their convenience without prompting, the synchronous category does not allow for this as it is instant [20].

In this study, the intention is to provide a detailed account of the application of an AODF in the collection of qualitative data from a group of discussants who would ordinarily have been difficult to access based on their locations and time zones. In this wise, the AODF was utilized as a replacement of the conventional focus group discussion which appears to be prevalent in contemporary BE research.

2.2. Asynchronous online Discussion Forums as Focus Groups

As mentioned earlier, AODFs have been likened to conventional focus group discussion exercises albeit conducted on an IMC platform to engender wider participation [26]. Lim and Tan (2001) [17] compare the features of a focus group discussion forum and AODF and conclude that the AODF fared better. Aspects were the AODF was found to have proven advantageous in the comparative exercise include: convenience, reduced instances of social interference, reduction in group-think as individuals could air their views without coercion, opportunities for reflection by the discussants and adequate control was provided to facilitators. Furthermore, transcription was made easier given that discussants were expected to provide their opinions in textual format. Most of these advantages have been highlighted in recent studies such as [17]. Conversely, scholars have also identified the failings of the AODF in terms of the high incidence of discontinuous threads, the need for participants to possess the requisite computer literacy skills as well as the absence of non-verbal clues [17, 12].

Based on the foregoing, this study was carried out to buttress the salient benefits accruable from the deployment of AODFs in the collection of qualitative data by BE researchers. This is considered imperative in view of the increasingly new reputation of BE professionals as a 'hard to reach' sample owing to peculiarities associated with the industry.

2.3. The Built Environment domain and its 'hard to reach' sample

Role players within the BE context are often occupied on projects with tight time schedules. It is becoming increasingly difficult for researchers conducting studies within this context to reach them and elicit their views pertaining to problems beleaguering the industry. However, qualitative data remains critical to the development of context-dependent theory as well as its usefulness in gaining both in-depth understanding of a phenomenon as well as obtaining rich descriptions of happenstance in within a context [6, 9]. The peculiar nature of the BE context makes the elicitation and subsequent use of qualitative data imperative.

Yet, the BE is a domain with a high turnover rate among role players given its task-based nature. Individuals exit the scene upon completion of assigned tasks. This transition and the fact that these role players are often located at several locations poses a significant challenge in scheduling interviews or focus group discussion sessions with them. Often, this is responsible for the incessant reportage of low response rates or participant apathy in qualitative research projects. As such, this study will highlight the utility of the AODF in overcoming identified challenges through a BE-centered study.

2.4. The Study Context

As part of a wider study seeking to investigate the implementation of socio-economic policies through procurement of oil and gas infrastructure in a developing country context, the researcher was confronted with the need to develop a framework for the proposed investigation. Having opted to situate this study within an organizational theory and systems thinking praxes, the researcher was confronted with the challenge of selecting an appropriate methodology for conducting an organizational diagnosis of the infrastructure procurement and delivery system. In the search for this methodology, it was agreed that such a methodology should not only enable but a diagnosis of the entire process of procuring and delivering infrastructure but also highlight in the extant relationships and responsibilities of the parties to the delivery process. Basically, such methodology should be able to describe in absolute terms the implementation framework for the procurement and delivery of oil and gas infrastructure in that country context as only such a representation would engender a succinct understanding of the entire process from a systemic perspective. Also, the implementation framework to be depicted in the proposed vignette will enable an accurate representation of the interorganizational relationship existing between the parties to the implementation process and the control and coordination points- items considered essential for systemic diagnosis of organizations.

Upon the probe of existing systems thinking, organizational theory and cybernetics theory literature, the researcher came across the term systems cybernetics and eventually, systems viability or viable systems theory as propounded in the seminal works of Sir Stafford Beer [4]. In the aftermath of a review of the viable systems approach to organizational viability and the conclusion of further inquest into its provenance in the organizational diagnosis context, the researcher arrived at the realization that the viable systems model (VSM)- a model premised on the principles of systems viability had only being applied towards diagnosing conventional organizations [14]. In this study, conventional organizations are considered as organizations that have a significant degree of permanence as when compared to organizations with a great degree of temporality. Organizations in the latter category are termed temporary organizations and, in the context, where such organizations consist of a plurality of organizations striving to deliver a certain product or service, they are termed temporary multi-organizations (TMO) [23]. The oil and gas infrastructure procurement and delivery system, hereinafter referred to as an Infrastructure delivery system (IDS) can be described as a TMO. This is because of the plethora of different organizations working in different capacities to deliver on the project objectives. Any diagnosis of the system will not be complete if it does not investigate the relationships between these organizations. As such, the researcher was unsure about the applicability of the VSM in the diagnosis of the IDS. There was an imminent need to reach out to system thinking as well as cybernetic experts to establish the model's applicability in this context.

Finding a community of experts, both in an individual and group capacity proved to be very arduous task. However, per chance, the researcher stumbled on two closed groups on LinkedIn housing communities of practice in the viable systems model and generic systems thinking. These groups will be referred to as VSA and ST groups respectively. Upon the identification of VSA and ST, the researcher proceeded to engage with the group administrators for admission onto these platforms.

The researcher obtained access to both platforms just a week apart with the VSA granting access first before the ST. In keeping with terms of disclosure, the researcher notified the two administrators of his intentions to utilize the platform to elicit data through InMail. The administrators requested for excerpts detailing the objectives of the study and some of the questions that may be asked. After a consideration of the questions and the objectives, the researcher was granted permission to carry on with the questions based on an agreement not to disclose member's pictures and names on publishable material. However, this was not the case in the ST group as the administrator informed the researcher that the questions being posed were out of sync with the interests of the group's membership. The consent obtained from the VSA was expected as it was a closed group with membership only open to persons with interests in viable systems theory, viable systems models and the real-world application of both theory and model.

The researcher created a separate platform within the wider platform with a note informing members of the study that was being carried out and the reason why their opinion was being sought. Individuals who were interested in the study were asked to indicate their interest by liking the introductory statement posed by the researcher. In total, 46 likes were received over a three-day duration. At the time of the study, VSA had membership of 431 individuals hence representing an estimated 10% of the total membership. The researcher, serving as a facilitator introduced new threads to deal with different questions which were aimed at achieving the study's objective. The exercise lasted for a duration of approximately seven (7) months, between July 2012 and February 2013. However, over this period, only 32 discussants participated in the various threads with active participation recorded for 17 discussants. Active participation refers to discussants who contributed more than once across the six discussion threads established over by the researcher. To the researcher, this was an indication of the acceptability of the study and the protocol utilized in eliciting data from the discussants. Table 1 details the number of threads, the number of posts on each thread and the number of discussants and active discussants who contributed to each thread.

Table 1. Discussion Threads, Posts and Discussants

Thread	Number of Posts	Summary of Discussants	Number of Active Discussants
1	49	34	17
2	72	21	17
3	38	18	17
4	23	17	17
5	85	19	17
6	27	17	17
6	294	126	17

Source: Author's fieldwork (2014)

From Table 1, the intensity of the discussions on the AODF can be deciphered accordingly. The number of posts mentioned exclude the posts made by the researcher during facilitation. Table 2 provides the demographics of the active discussants.

Table 2. Demographics of Discussants

Code	Position	Expertise	Relevant experience (years)	Location
A	Professor	Sustainable Business Models	22	United Kingdom
B	Associate Professor	Construction Informatics	19	Oman
C	Professor	Systems thinking application in Business	30	Switzerland
D	Research Fellow	Systems thinking	7	India
E	Senior Project Manager	Systems thinking application	12	Switzerland
F	Management Consultant	Target Operating Models development using VSM	25	United Kingdom
G	Management Consultant	Systems thinking application in Business	23	Germany

H	Software Expert	Systems thinking and Cybernetics	28	United Kingdom
I	Chief Solutions Architect	Cybernetics and Change Management	28	Canada
J	Solutions Manager	Systems Integration	19	Switzerland
K	Professional Consultant	Leadership and system design and modelling	14	Italy
L	Business Solutions Expert	Systems dynamics and Next generation Enterprise	14	Italy
M	Management Consultant	Organizational analysis and design	18	South Africa
N	Management Cybernetician	Management Cybernetics	32	United States of America
O	Financial/ economic Analyst	International/policy development	23	Netherlands
P	Researcher	Systems thing in Construction	18	Hong Kong

Source: Awuzie (2014)

The researcher obtained rich data from the postings made by these discussants. A look at the experience of the discussants- an estimated average of 19.5 years- indicates that the researcher was able to obtain relevant viewpoints on the suitability and applicability of the VSM and its underlying theory in carrying out organizational diagnosis of the IDS. However, it is beyond the scope of this study to discuss the views elucidated in those posts. As such, the study will concern itself with reflecting on the usefulness or otherwise of the AODF in the elicitation of data from systems thinking experts across the world.

2.5. Reflections on the Asynchronous Online Discussion Forum's Utility

The AODF and other online discussion forums have been presented as veritable platforms for knowledge creation and exchange across targeted groups or individuals in geographically dispersed locations in a cost-effective manner. Yet, of interest to this study, is its use in facilitating data collection for qualitative research. In subsequent sections, the researcher will reflect on the aspects of the ADOF, highlighting its utility and identifying challenges associated with the approach.

Merits

During the study, the researcher identified the following advantages of the ADOF;

Ease of transcription

The ADOF platform allowed for the automatic generation of transcripts from discussant postings. This was a significant advantage when the labourious and expensive nature of transcribing interviews is considered. This advantage happens to be the most common advantage as it has been mentioned in similar studies [8, 17, 13]. The researcher was able to generate the entire transcripts from the LinkedIn group platform.

Control of discussion patterns

The facilitator's ability to control the tone and direction of discussions between discussants during conventional focus group interview sessions remains a salient challenge. The facilitator is expected to manage the power-relations and dynamics which are usually present even within homogenous groups during the discussions. Such dynamics usually affect the validity of the views expressed therein as certain discussants are afraid not to upset their colleagues or organization even when confidentiality and anonymity has been guaranteed by the facilitator. The purposive recruitment of highly homogenous groups has been referred to as a panacea for resolving this challenge, but the efficacy of such selection process remains imagined. But in the ADOF study described, the facilitator did not notice any situation which highlighted the incidence of such scenarios from the posts.

Coverage of wide geographical area

The coverage area of the discussant cohort can be deciphered from Table 2. This is another salient advantage of the ADOF. It brought together professionals who were involved with the Viable Systems Model thus providing a platform for multi-, inter-, and transdisciplinary co-creation of knowledge on the applicability and suitability of the VSM for diagnosing TMOs. Hence enabling co-creation of knowledge: one of which the identification a set of pre-set themes which the researcher used in outlining the shortcomings of the IDS that was being diagnosed in the wider study.

Convenience

Based on its asynchronicity, the platform proved to be convenient for the researcher and the community of experts as they were only obliged to post comments at their convenience. Also, this enabled them to engage in thoughtful reflections before responding to previous posts on the threads. It prevented spontaneity among the discussants as would have been the case if the event of focus group discussions or synchronous online discussion forums. The researcher was notified concerning new posts through an alert as enabled by the LinkedIn, hence not needing to remain online in wait of new posts.

Relevance of contributions

Because of the purposive nature of discussant recruitment and the willingness of individuals to partake in the study without coercion, the discussions were found to be relevant to the theme of the study. This observation contributed to a more than 50% retention rate in the discussant cohort as shown in Table 1. This mere fact serves as a morale booster for the researcher as it reinforces the salience of the study being undertaken to the world of practitioners, beyond the academic disciplinary boundaries but also stretching into the real-world context. The number of discussants was not considered an anomaly as conventional focus groups will usually consist of between 7 and 10 discussants whereas in this case, 17 active discussants were identified from the threads.

Challenges

The AODF as deployed in this study did not come without challenges. One of such challenges is discussed below.

Sustaining discussions on threads

The use of the AODF was not a smooth on after all as the researcher encountered difficulties with sustaining the tempo on threads. At some points the threads appeared dormant despite prompts from the researcher to encourage further contributions. Also, in some instances the researcher had to refer to sister threads on the same matter or some other discussant's opinion to see if that will lead to renewed interest. Whereas this worked in some instances, it failed to do so in other instances. Judging from contents of relevant literature, this is a common issue with AODFs [15, 10]. Perhaps this may be because of the ling time frame for data elicitation. However, the researcher felt constrained in deciding on when to stop seeking for new contributions as saturation was not reached on two of the questions that were posted on the platform. Eventually, the choice of the appropriate time to stop posing questions was influenced by the timelines of the wider study. Yet, two years after, comments were still being posted on the platform, obviously due to its asynchronicity, until the researcher sought the permission of the administrator to close the threads.

3. Conclusion

The recruitment of interviewees/discussants to participate in qualitative BE research projects has been identified as a challenge to most BE researchers. Besides this, the labourious and expensive nature or transcribing qualitative data posed another challenge to these cohort of researchers. As a result, these cohort seem to overtly rely on the quantitative methods of data collection. This is evident in the prevalence of quantitative research projects within the BE domain.

Aware of these challenges, this study set out to provide an exposé into the utility of IMC techniques such as AODF in surmounting these challenges. It relies on a study conducted between 2013 and 2014 within which the AODF was deployed towards accomplishing certain aspects of the study. Accordingly, a highlight of the advantages accruing from the utility of the approach and the challenges, was provided herein by the researcher. From the evidence presented in

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the paper, it is evident that the benefits far outweigh the disadvantages. However, it must be noted that the AODF's utility is predicated on the level of knowledge of probable discussants on the usage of the internet as well as access. In furtherance to this, it should be noted that the cost-effectiveness of the approach as used in this study, resulted from the use of an already established platform- LinkedIn. It is believed that this will be different if the researcher must develop a bespoke platform for his study.

It is expected that this study will contribute in generating interest around the use of IMC techniques such as the AODF for qualitative data collection purposes within the realm of BE research.

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Attributes of Farmers' Willingness in Participatory Irrigation Infrastructure Management

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Abstract

Pakistan is agro-based economy. Agriculture in Pakistan relies upon a vast network of canals that is said to be the world's largest contiguous irrigation system. However, over a period of time, the system is deteriorating and becoming hard for the government to coup up with its financial costs. This has led the government to decentralize the irrigation network by means of introducing participation based development programs in various regions to transfer canal ownership to the farm owners. Participation based development has been advocated for its potential to achieve community level success, and to empower the end-users. Participatory development approach has also proven to reduce the burden over public funds. Nevertheless, previous studies have shown that the willingness of the members (i.e., end users) to be the part of a participatory development program plays a vital role in securing success. Following this notion, this study attempts to understand the attributes of farmers' willingness in a provincial level participatory development program. This study identifies that 'willingness' of a farmer to participate is a dynamic process that extends far beyond farmers' mere agreement to the norms of project, but it further requires continued support and action throughout the project life. As a matter of fact, the willingness of farmers' depends upon a range of factors that are further influenced by cultural and geopolitical contexts. This research presents an abstract model indicating factors attributing farmer's willingness in pre-project commencement and during project execution. Unstructured interviews and a questionnaire survey are used to identify attributing factors and to develop willingness model. This paper concludes with a discussion over the role of willingness in achieving targets in case study project. This study will help academicians, researchers and policy makers with better understanding of the role of farmers' willingness in participatory development approach programs.Click here and insert your abstract text.

Keywords: Participatory development; Willingness; Irrigation; Infrastructure Management;

1. Introduction

Agriculture plays a vital role in economic and socio-cultural domains of Pakistan. It is said that the majority of the working class population is directly or indirectly attached with agriculture and its associated industries [1]. Agriculture in Pakistan is augmented through the Indus river system, which is said to be the world largest contiguous irrigation system [2]. The Indus river system consists of three barrages, 14 canals. The total irrigation system, consisting of many distributaries and minor from main canals, is stretching over 64,000 km. Nevertheless, due to rapid growth in population that is further coupled with public sector inefficiencies and persisting corruption in government funds has left the existing irrigation infrastructure is in a deteriorating condition that is not able to feed to all of the fertile lands. It is noted that persisting problems with the irrigation infrastructure are known since early 1980. Such problems are included financial gaps, poor water revenue collection from farm owners, lack of extended

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infrastructures, vast inequalities in the distribution of canal water and consequent low agricultural productivity [3, 4, 5]. Nevertheless, the prevailing socio-culture trends and dominating political elements are also responsible for such a worsening situation. Historically, socially and politically dominated landowners are witnessed to bribe irrigation staff to draw water more than their allocated share; so as to increasing inequality and putting system at stress [3, 6, 7].

Facing such a complex problem that is interwoven with socio-cultural, geopolitical and economical domains has then paved a way for the policy shift to decentralize the existing irrigation infrastructure to a participatory-based system. Nevertheless, long before such a policy shift, the irrigation watercourses are historically being collectively operated through watercourse associations. The policy shift planned to disintegrate the government owned the irrigation system in to small autonomous units, which should be regulated by a provincial level agency. In the province of Sindh, such an agency is developing and known as Sindh Irrigation and Drainage Authority (SIDA).

The origin of SIDA was initiated in 1997 with the government's plan to rehabilitate the national irrigation infrastructure under the umbrella of 'National Drainage Program (NDP)'. The program was assisted by the World Bank and the Asian Development Bank. The reforms arose from the NDP included the transfer of the irrigation system from provincial irrigation departments to the multitier autonomous bodies consist of end-users (i.e., farmers) with clearly defined roles and responsibilities [8]. Consequently, the Provincial Irrigation Department Act (PID act 1997) was passed, in each province of Pakistan, to design legal and administrative frameworks to develop autonomous and financially self-reliant participatory irrigation management (PIM) based Area Water Boards (AWB). In the Sindh province, PIDA Act 1997 was further amended in the year 2000 to form the Sindh Water Management Ordinance (SWMO2000) [9]. The SWMO 2000 then led to the establishment of SIDA with its 3 incorporated AWBs. The SIDA then defined detailed functions and responsibilities of AWBs including tertiary watercourse associations. The three AWBs were built upon three canals, i.e., i. Ghotki Feeder (hereinafter described as 'north'); ii. Nara Canal (hereinafter described as 'center') and iii. Left Bank Canal (hereinafter described as 'tail'. The figure 1 shows the map of the Sindh province and three respective AWBs.

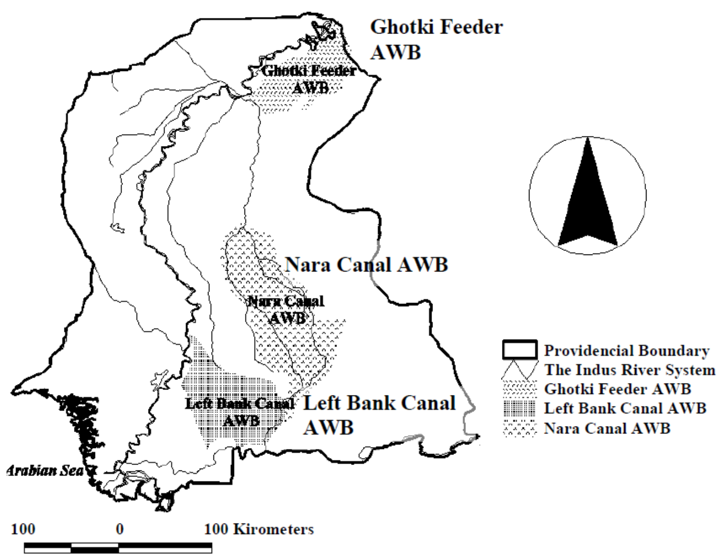

Fig. 1 Map of Sindh Province and SIDA's three Area Water Boards

1.1. Farmers' Willingness

The SIDA has been criticized by the farmers and media for not delivering anticipated contributions. It is also reported SIDA is also not able to increase the capacity of farmers especially in terms of their adherence to the new patterns of PIM as it is conceived at the inception of the SIDA. Previous researches [10] found numerous issues that are hindering the progress of SIDA, most of the issues are also confirmed by this study. Among such issues, one of the most prominent was the farmers' willingness to be the part of the program. Willingness not only meant to agree to participate, but to adhere all of the protocols and norms of the planned project.

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The unstructured interviews conducted for this study has revealed that "willingness of farmers" is not a static factor that has been irrationally attempted to achieve by means of community mobilization and capacity building, rather it's a continuous process that is only initiated with these two factors. As a matter of fact, the willingness is a continuous process that has to be initiated from the project conception to the project completion. Nevertheless, there are certain factors that abstractly define the willingness, out of which few are required to vitalize before a project is entering in the execution stage, while others are needed to be presented throughout a project lifetime. This study has found 10 attributing willingness factors, which are found necessary in a decentralized irrigation water distribution project of SIDA. Next paragraphs further define the identified factors.

2. Research Methodology

This research is based upon unstructured interviews with the stakeholders associated with the SIDA, i.e., SIDA staff and the farmers associate with AWBs. This study is accomplished in four parts; i.e., (i) review of open literature (ii) unstructured interviews with the stakeholders, (iii) questionnaire survey and (iv) data analysis and interpretation of results.

2.1. Literature Review

The open literature on policy issues in decentralizing irrigation infrastructure in Pakistan is referred to collect insights on functionality of SIDA. Along with policy issues, various research papers and other publications citing management issues in SIDA are also reviewed, out of which some have been cited in the introduction part of this paper.

2.2. Unstructured Interviews

The literature review is then followed by unstructured interviews with stakeholders that included SIDA officials, farmers and farm owners and the consultants. Nevertheless, such interviews were limited to the few numbers of the officials and farmers from different locations in the province. The unstructured interviews were consist of open end questions to gain more insights on the issues that were collected from the literature. Many key issues were highlighted, most importantly, it is highlighted that the new decentralized system has not fully adhered by all stakeholders; and people see the old government system more efficient.

2.3. Questionnaire Survey

The literature review and the unstructured interviews has then led to the revelation of issues and ideas that have impeded the adoption of participatory protocols of the newly decentralized irrigation system, out of which "willingness to participate" received high importance; and the similar is taken further to be researched for this study. The literature and unstructured interviews have resulted in specific factors attributing the willingness of farmers, based on which a questionnaire survey is conducted from all of the three AWBs. Identified factors are then presented to the respondents and are asked to rate it according to their satisfaction on a 9-point Likert scale. Figure 2 shows the 9-point Likert scale adopted for this research.

Extremely Dissatisfied (1)	Very Dissatisfied (2)	Moderately Dissatisfied (3)	Slightly Dissatisfied (4)	Neither satisfied or Dissatisfied (5)	Slightly Satisfied (6)	Moderately Satisfied (7)	Very Satisfied (8)	Extremely Satisfied (9)
o	o	o	o	o	o	o	o	o

Fig. 2 The 9-Point Likert Scale used to collect responses

2.4. Data Analysis

Table 1 shows the respondents demographics. For the ease of understanding, the respondents are divided according to their associated region; i.e., North, Center and Tail area. The river Indus enters in to the Sindh province from north and then flow from the center it meets with the Arabian Sea in the south. It has been noted historically that as the Indus river flows towards its tail end, the water quantity decreases and consequently tail regions receives relatively low quantities of water in comparison to the north and center regions. Therefore, such division will help us in understanding the responses with respect to the usual availability of water.

The questionnaire data is then analyzed through IBM's Software Package for Social Scientist (SPSS V.20). Frequency analysis and weighted mean score rankings [11] are then performed to confide responses and to indicate stakeholders' perception over identified willingness attribute. It is found that respondents of different locations have quite a varying view, which is discussed in detail in the following section.

Table 1 Respondents' demographics

	Location			Total
	Center	North	Tail	
Farmer	12	26	16	54
SIDA	7	4	3	14
Total	19	30	19	71

Table 2 Identified attributes of farmers' willingness and general mean scores of each location

Sr#	Willingness Attributes	Project Location		
		North	Center	Tail
Pre-Project Execution				
1	Proper identification of incentives for the farmers	7.1	6.6	3.9
2	Capacity building efforts by the SIDA	5.5	4.4	3.5
3	Level of trust between SIDA staff and members of Water users Association	5.7	6.3	5.7
4	Farmers' willingness to be a part of the project	7.6	7.7	7.5
During and after project execution				
5	Trusted and efficient leadership of AWB	7.2	6.9	6.7
6	Legal and financial consultations of farmers by the SIDA staff	5.0	5.9	3.9
7	Project cost incentive relationship	7.2	7.1	6.6
8	Efficiency of the constructed Works	8.3	5.6	5.6
9	Collective efforts of member of AWB	7.2	6.0	6.4
10	Available conflict resolution mechanisms	5.7	5.6	3.9

3. Discussions and interpretation or questionnaire survey results

Table 2 shows the list of identified factors, with their generalized weighted means for each location..It is evident from the table 2 that there is a difference of opinion on the willingness attribute across the province, and similar is the reason that all regions different in terms of achieved progress. It is also to be noted that the tail region has the least weighted mean scores. A similar trend is found when collected data is segregated with respect to different stakeholders, i.e., farmer, SIDA officials and the consultants. Table 4 shows the weighted mean scores of different stakeholders across the three regions.

3.1 Proper identification of incentives for the framers

The biggest incentive for a farmer to be a part of SIDA is to receive a fair share of water, which might have been uncertain under the public ownership of the irrigation infrastructure. Nevertheless, apart from a fair share other incentives, such as empowerment and improved infrastructure etc., must be identified and communicated to the prospect participant farmers. The knowledge of incentives drives the farmers to join the program and make them an active member of a participatory-based system. Lack of identification and knowledge of incentives may not only lead to a hindered project speed but also led participants reluctant to provide their potential input. Similar is the case of SIDA in the tail region, where general scores are observed as low as 3.9; while specifically farmers' score is even lower at 3.1. On the contrary, SIDA official and the consultants are more confident with the score of 8.3. Such a contrasting results shows that there is a gap between farmers and SIDA in understanding of incentives. Or alternatively the new decentralized system has failed to deliver incentives to the farmers in the tail region. In the northern and the center region, the farmers are however moderately and slightly satisfied, which is probably due to the relatively higher quantity of water available in the region. In both, north and central regions, the SIDA officials are scoring almost similar to their counterparts, i.e., farmers.

Table 3 Weighted mean scores of different stakeholders across the three regions

Sr#	Factors	Location of the Project						Consultant
		North		Center		Tail		
		Farmer	SIDA	Farmer	SIDA	Farmer	SIDA	
Pre-Project Execution								
1	Proper identification of incentives for the farmers	7.0	7.3	6.2	6.7	3.1	8.3	8.3
2	Capacity building efforts by the SIDA	5.2	7.5	3.0	5.0	2.7	7.7	8.3
3	Level of trust between NPIW staff and members of Water users Association	5.6	6.3	6.0	6.0	5.2	8.7	8.0
4	Farmers' willingness to be a part of the project	7.7	6.7	7.9	7.3	7.4	8.0	8.0
During and after project execution								
5	Trusted and efficient leadership of SIDA	7.3	6.3	6.7	6.3	6.6	7.0	9.0
6	Legal and financial consultations of farmers by the SIDA staff	4.7	7.0	5.1	6.0	3.3	7.0	8.7
7	Project cost incentive relationship	7.2	7.0	7.2	6.5	6.4	7.3	8.0
8	Efficiency of the constructed Works	8.3	8.5	5.5	4.4	5.1	8.7	8.7
9	Collective efforts of member of AWB	7.3	6.3	5.3	6.0	6.4	6.7	8.7
10	Available conflict resolution mechanisms	5.5	7.0	5.1	6.0	3.4	7.0	7.0

3.2 Capacity building efforts

Policy makers develop a set of project protocol, i.e., rules of conduct, and then social organizers extend it to the community to enhance their capacity of understanding participatory based system that is planned to implemented [12]. The ref [12] further emphasizes, from his experience of a famous participatory based development project in Karachi Sindh, on 'social infrastructure building' before inviting community to participate in a project. Initiating project without confirming that the community has sufficiently adhere the concept may led to no or skeptical participation; which may further lead to a non-cohesive participant behavior. Such a situation is observed while conducting interviews and questionnaire survey for this study. It is noted that at many places, especially in the tail regions, the farmers are unaware of the true means of the "participatory based system". As a matter of fact, capacity building effort receives one of the least scores, for both general and group- wise, among ten willingness attributes. However, table 3 shows that SIDA officials are quite confident about their efforts on "capacity building", which demarcates another gap between SIDA and farmers.

3.3 Level of trust between farmers and SIDA Staff

Trust is factor that builds faith of the community on the project and on the promoting agency itself. The faith then drives positive energy in farmers, which can lead to participate with their full potential. The unstructured interviews and the survey have reflected almost similar perception from farmers and SIDA officials across the locations. The scores have shown that both farmers and SIDA staff have not fully developed the trust over each other. Such lack of trust may be attributed to the traditional role of irrigation staff and the uncertainties associated with the availability of the water. It is also to be noted that such lack of trust can also attributed to the historical role of irrigation staff that is highly influenced by the socio-political pressures to favor selected ones only; and most notably the persisting notion of high rates of corruption [10].

3.4 Farmers' willingness to be a part of the project

Farmers' willingness is a prime factor that is derived based on the three factors discussed earlier. Such dependence is confirmed through the interviews from the farmers throughout the studied locations. The knowledge of the participation incentives, full knowledge of working protocols and trust on the fellow farmers and the government agency staff let farmers participated with full motivation and energy. Confirming to the three factors can alone lead farmer to engage in the program till the end. Among general scores, all of the three locations have scored it 7.5 and above. In the group-wise scores, groups from all locations have scored 7.4 and above except SIDA staff in the north has rated it as 6.7, which is indicating slightly lower rate of farmers' agreement to participate. Lack of farmers' willingness can be attributed to the farmers' low scores of 'capacity building efforts' and 'level of trust' in the same region. However, on the contrary, the center region has depicted high scores from both farmers and the SIDA staff, while having very low scores of capacity building. This can be due to the fact that the center region has a higher literacy rate and therefore farmers there are more educated and have prior knowledge and incentives associated with the participation based development; and therefore higher rate of farmers' willingness is observed.

3.5 Trusted and efficient leadership of AWB

Trusted leadership definitely takes the association to a successful and smooth operation; and enforces farmers' willingness to be an active part of the project. The high scores on 'trusted and efficient leadership of AWB' have shown that this attribute is sufficiently presented across all regions, with a slight deferment. The north has depicted highest mean scores of 7.2, with 6.9 and 6.7 for center and tail regions respectively. In the group-wise scores, the tail farmers has demonstrated relatively higher mean scores of 6.6, with 6.3 score for both the north and center region. It shows that farmers at the tail region have better cohesion, irrespective of other difficulties, such as low water availability.

3.6 Legal and financial consultations of farmers by the NPIW staff

The ref. [13] found that effective transfer of operation rights to the farmers requires continuous support. It becomes necessary to provide guidance to the participant farmers to deal with legal and most notably financial matters on running and managing farmer organization and AWB under the newly decentralized system. This study finds that at many places the AWB members still lacks the necessary knowledge about running financial matters, especially when bringing balance between the revenue collection and performing operational and management tasks. Similar is the reason that this particular attribute has received one of the least general mean scores of 5, 5.9 and 3 for north, center and tail regions respectively. The lowest general mean scores of 3 by the tail region indicates a dire gap of legal and financial support. The gap is also evident from the group-wise mean scores, where a notable difference is noted between the farmers' and SIDA staffs' scores in all of the three regions. The largest difference is observed at the tail region, where farmers have scored 3.3 and SIDA staff has scored 7. Unaware of financial knowledge and support has identified as a potential factor causing deterrence in farmers to bring in full potential to the project, as it induces uncertainty and doubts on the participatory system.

3.7 Project cost incentive relationship

A positive relation between the cost paying and incentive receiving is mandatory for active participation of the farmers. This particular willingness attribute is usually a part of project design, which is also often compromised due to program implementation inefficiencies, socio-political pressure and ground realities; such as it was the case in SIDA. In spite of the evidences in open literature [10], the respondents from the north and the center has mean scored 7, and the tail region has scored 6.6. Quite similar trend is reflected by the stakeholders in the group-wise scores. This indicates that the participant farmers are satisfied to some extent with payoff of their participation.

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3.8 Efficiency of the constructed works

Satisfaction with the development works and the resultant efficiency provides the participant farmers with trust in collective efforts and in the efficiency of the program, which assures their active participation in the project. Among all three regions, north has scored the highest with 8.3; while the center and tail regions have reflected relatively lower scores of 5.6. In the group-wise scores, the farmers have reflected even lower with 5.5 and 5.3 for the center and the tail region respectively; which is indicating their relative dissatisfaction with the development works. The SIDA staff in the center region has almost similar scores as farmers, while in the tail region SIDA has scored quite high as 8.7, which indicates another gap between the partners.

3.9 Collective efforts of member of FO and AWB to achieve targets

Collective effort is the prime notion based on which the whole concept of participatory irrigation management rests. Collective efforts of the members not only bring cohesiveness to the members but also greatly influence the pace of project to attain the targets. Collective efforts are refereeing that every member is willing to provide the required share of input to the project, which if some members are not willing to will have a team breaking reaction. In this study, the north region has depicted the highest mean score of 7, with scores of 6 and 6.4 for center and tail regions respectively. In northern region, the farmers are found surer about their collective efforts than to SIDA parts. In center region, the farmers have depicted the lowest scores of 5.3, which indicate cohesiveness problem among the AWB members.

3.10 Available conflict resolution mechanisms

Sindh is province where quarrels based on political affiliations and or on tribal association are common, especially in rural areas. The establishment of SIDA has then attempted to combine participants which are already in quarrels, or at least have grudges against other participants. The ref [14] reported that majority of quarrel in rural areas of Pakistan starts from the arguments over sharing irrigation water. In such a dilemma, the availability of rigorous conflict resolution mechanism is inevitable. The SWMO act (2000) provides a framework for conflict resolution among members of AWB. In this study the farmers have rated the existing system very poor with the scores of 5.5, 5.1 and 3.4 for north, center and tail regions respectively. On the contrary, the SIDA staff and the consultants have rated it as satisfactory with the lowest score of 6 and highest score of 7.

4. Conclusion

This study has attempted to analyze farmers' willingness to be the part of SIDA. A total of 10 attributes of willingness has been identified; for which responses indicating their satisfaction, from the farmers and the SIDA staff are collected. A wide gap is observed for almost each of the identified willingness attribute. SIDA staff from all locations has reflected their satisfaction with a varying degree, while the consultants have also shown their satisfaction on all willingness attributes, but with quite higher ratings of 'very' and 'extremely' satisfied. It should be noted at none place the SIDA staff has reflected 'extremely satisfied' for willingness attributing factors. For most of the factors their satisfaction is between 'slightly satisfied' and 'very satisfied'.

Among farmers, the northern region has reflected the highest rates of satisfaction, which shows their promising willingness to participate. The majority of their low mean scores are nearer to the neutral state, such as 4.7 for 'legal and financial consultation by the SIDA staff, and 5.2 for the 'capacity building efforts by the SIDA staff'. The farmers at the center and the tail region have reflected relatively lower satisfaction. Majority of their means scores have merely crossed the 'moderately satisfied'. The farmers at tail end have responded the lowest means scores, such as 3.1 for the 'proper identification of incentives' and 3.3 for 'legal and financial consultation by the SIDA staff'. This has shown that there is dire to need to fill in the gaps between farmers and the SIDA staff. Special reforms and efforts are mandatory to bring in the farmers at tail end and to focus their issues. It is highly recommended that capacity building efforts and the financial consultation of the farmers must be strengthening with new protocols.

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Best Value Procurement – The First Experiences from Norway

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Abstract

Best Value Procurement (BVP) is a method for contractor selection and project management, which seeks to increase project value by emphasizing the competence and expertise of the contractor. Several studies in the US and Netherlands indicate promising results. The method is new to Norway and pilot projects in the construction industry are testing the method. Limited research has been done to explore the experiences of these pilot projects. This study investigates how BVP was implemented in practice and the experiences with the method to develop suggestions for future projects on how BVP should be performed. The research was carried out through a literature study and two Norwegian case studies. A building project and a medium-size infrastructure project in the Norwegian public sector were explored through nine semi-structured, in-depth interviews and document studies. The findings show that the practical use of BVP aligns with the theoretical approach. However, since the method is new in Norway there are some challenges, such as the contractors' lack of knowledge of and experience with the BVP method. This may reduce the potential project value. The conclusion is that BVP is an effective and promising method for contractor selection and project management. However, for the success of future projects using the method, project owners may benefit from providing contractors with more knowledge of and experience with BVP. This can be done by training and by being persistent in using BVP in future projects.

Keywords: Best Value Procurement (BVP); Early Contractor Involvement; Public Procurement; Public projects; Norway

1. Introduction

Projects in the construction industry often suffer from cost and time overruns [1]. Various reasons for this have been suggested in the literature, but a recurring factor is traditional project procurement methods in which contractors are contracted sequentially. This leads to silo thinking and a lack of goal alignment between the project owner and the contractors. Several studies indicate that earlier contractor involvement can increase the project value and reduce the conflict level between the project owner and the contractor [2,3].

One of the methods that can be used for early contractor involvement is Best Value Procurement (BVP). BVP is a method for vendor selection and project management, which seeks to increase project value by emphasizing the competence and expertise of the vendor. The method utilizes previous performance data and interviews with key personnel to find the presumed best value vendor for the current project. The vendors compete based on project capability, their ability to identify risk, the additional value they can provide, interviews, and price [4]. The competition within these factors should lead to the selection of the vendor who offers the best value. BVP can be applied to procure all sorts of vendors, be that contractors for public works or service suppliers. This paper addresses how BVP is applied to construction projects, and in the following the word 'contractor' is used instead of the more general term 'vendor'.

Several different BVP methods exist, but this paper addresses the method that was developed by Dean Kashiwagi at Arizona State University in 1991 [5]. The method has been used with great success in the US [6]. BVP was

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introduced to the European market in 2005 when pilot projects were implemented in the Netherlands [7]. The experiences with the method in the Netherlands have been promising, and the method is now being tested in Norway.

Despite the promising experiences in the US and Netherlands, several challenges have been identified with the method [2]. For instance, the method is challenging to implement in the client's organization, and it demands thorough training of both the client and contractor [4]. Furthermore, the public procurement rules in EU and Norwegian law set certain limitations to the use of innovative procurement methods for public project owners. Public project owners must adhere to the public procurement principles of competition, equal treatment, and non-discrimination. As a result, the original BVP method must be implemented in a modified form for public project owners in the EU [8]. In addition, there are some practical barriers to implementing such methods of early contractor involvement, such as traditional culture and contracting practice [9].

Although several studies have been conducted on the use of BVP in the US and Netherlands, there is a knowledge gap on the use of BVP in other countries, including Norway. The purpose of this paper is therefore to study the introduction of BVP to the Norwegian construction market. By studying the practical use of BVP, and gathering experience data from the pilot projects, the knowledge database on how BVP can be implemented in the future may be strengthened. This paper addresses the following research questions:

- How was BVP implemented in practice?
- What are the experiences with BVP?
- How should BVP be performed in future projects?

This study is limited to two Norwegian cases that are medium-sized municipality projects. Furthermore, both cases are still in the execution phase. Therefore, the generalizability of the findings may have limitations.

2. Research methodology

The research was carried out through a literature study and two case studies. The literature study was conducted in accordance with the recommendations given by Arksey and O'Malley [10]. Search words such as BVP, Best Value Procurement, Best Value, PIPS, EU and combinations of these were used. Citation chaining was used for important documents. The objective of the literature study was to develop a theoretical background on how BVP should be performed, and to gain insight in previous experiences with the method.

To address the research questions, two cases were studied according to the recommendations by Yin [11]. The case studies involved two medium-sized municipality projects in the Norwegian public sector: one building project and one infrastructure project. The main characteristics of the case projects are presented in Table 1.

Table 1 – Main characteristics of the case projects

Project name	Type and complexity	Cost (EUR)	Role of interviewees
Flatåshallen Flatås sports club	**Building project** Construction of a sports hall, indoor football pitch, offices, and canteen. Total size: Approx. 6 200 m^2. Expected completion in August/September 2018.	7 200 000	Project leader (project owner) Project leader (contractor) Member of grading group Member of grading group Losing bidder
Metrobuss Trondheim municipality	**Infrastructure project** Construction of a four-lane highway, bicycle and walking trails, and two metrobus stops. Length: Approx. 800 m. Expected completion in July 2019.	7 700 000	Project leader (project owner) Project manager (project owner) Project leader (contractor) Member of grading group

The cases were investigated through in-depth interviews with key personnel in the two projects, in addition to a losing bidder. A total of 9 interviews were conducted with interviewees from both the project owners' side and the contractors' side. As such, both the client's and the vendor's perspective have been examined. The interviews were conducted in a semi-structured manner, with an underlying interview guide containing central questions. The interview guide helped to give consistency through the different interviews, and to increase the validity of the data. The interviews were held face-to-face, which is beneficial for sharing information. The interviews lasted from one to one and a half hours. The interviews were recorded with permission from the interviewees. Transcriptions of the interviews were afterwards sent to the interviewees for approval to increase the reliability of the data.

To supplement the data obtained through the interviews, document studies were also carried out. Access to project documents was given through project intranets. The documents included tender documents, contracts, and design plans.

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3. Theoretical framework

Although BVP seems to be a fairly detailed method for project procurement and management according to literature, it does not contain any set rules for how it should be implemented. Thus, there are various ways to apply the method. However, the main principles and philosophy of BVP must be applied in order for the method to work as proposed [12]. The main reference on how the theoretical model of BVP should be implemented is the book written by the originator of the method – Dean Kashiwagi [6]. However, in the European context, van de Rijt & Santema's 'Prestatieinkoop' [4,13] books are perhaps more important. This is because the method is adapted and presented in these books in a way that seeks to fulfill EU public procurement legislation requirements. A variant of this method is the approach that has been used in Dutch BVP projects. Since the Dutch approach is the method that the Norwegian projects are based on, it is also the approach that will be presented in this section.

3.1. The principles of BVP

The basic idea behind BVP is that the contractor is the expert on how the project should be executed. The control over the execution of the project should therefore to a larger extent be transferred to the contractor. Conversely, the project owner's management, direction, and control of the project should be minimized. This is done by shifting decision making towards the contractor [6]. Furthermore, the risks of the project are not transferred from the project owner to the contractor, but rather the management and control of these risks [4].

A core principle of BVP is the use of *past performance information* to predict the performance of the contractor in the current project [14]. As such, it is important that the previous performances of the contractor are measurable, and that they can be substantiated with controllable documentation. Past performance information is an important part of the selection process, but the contractor's performance in the current project is also measured in the execution [4].

The main goal behind BVP is to increase the project value while shortening the procurement time and maintaining competition between contractors. The increase in project value means that the goals of the project should be fulfilled to the largest possible degree, while still minimizing the project costs [6].

Although the BVP method is based on the contractor's expertise, it is not necessarily based on a *trust* in the traditional sense of the word [15]. The need for trust should be minimized through principles of transparency and accountability. In other words, the contractor's provision of performance information should lead to the client not having to *trust* the contractor, but rather become certain about the contractor's expertise. Snippert et. al. [2] denote this as a calculus-based trust, as opposed to traditional, relational trust. However, a traditional trust relationship between the client and the contractor will typically be developed in the Selection and Clarification phase.

3.2. The four phases of BVP

To understand the BVP method, it is necessary to have insight in how the phases of the method work. BVP is typically conducted in four phases: *Preparation* (*Pre-qualification* as it is called by Kashiwagi [6]), *Selection*, *Clarification*, and *Execution*. These phases consist of different core elements and activities that may be applied to standardize the BVP procedure. In the following, some of the core elements from theory [4] and elements that have been identified in previous studies [16] will be presented.

1. The *Preparation phase* is the first phase. In this phase, the client and the contractor are prepared for the process of using BVP by receiving education and training in the method. The phase starts with the selection of a *sponsor* in the client's organization who is responsible for the BVP [4]. To gain training and insight in the BVP method, the involvement of an *external BVP expert* is usually beneficial. After that, a *core team* in the organization is selected and educated. The core team can for example consist of a project leader, a procurement leader, a representative from the management, and a person with competence in the type of project that is to be executed [4]. The use of *pre-qualification* – i.e., minimum legal and financial requirements for the contractors – may also be used. This is generally not recommended by van de Rijt & Santema [4], but it may be beneficial if there are many potential bidders [6]. Furthermore, a *core document* should be created. This contains information on the project scope, the project objectives, the weighting criteria, and the budget ceiling. The core document is to be released as information to the bidders [6]. In public procurement, BVP contractors are typically selected by the criteria of *MEAT* (Most Economically Advantageous Tender). Thus, other factors than price are evaluated. Since BVP uses an *open budget with a ceiling* – i.e., the project owner's maximum price is released as information to the contractors – the risk of procuring an expensive project is lowered, which yields room for weighting the criterion of price lower. Price is commonly weighted at around 25 % in

BVP projects [4]. When the core document has been created, the process of inviting contractors for a tender competition can be started. *Training sessions for the contractors* may be held as part of the process of conducting the tender competition, for creating awareness about BVP in the market and educating the contractors.

2. The *Selection phase* is the second phase of BVP. The goal of this phase is to identify and select the best value contractor. The Selection phase is typically conducted in three steps: 1) Evaluation of written documents from the contractors, 2) interviews with key personnel from the contractors, and 3) prioritization of the contractors according to evaluation of the written documentation, interviews, and price [4]. The phase starts with the contractors sending in their written offers, which consists of three documents: Project Capability, Risk Assessment and Value Added. In addition, the price is provided in a separate document. It is vital that the documents are short; no more than 2 pages each. This is an important part of maximizing the resource efficiency of the involved parties. Furthermore, the provision of dominant information is a key term: The information given in the written documents should be accurate, measurable and verifiable. To evaluate the offers, a grading group is used. However, *two or more independent grading groups* may also be used. This was done in the Dutch projects at Rijkswaterstaat [16]. The members of the grading group evaluate each document individually and set scores [4]. On the basis of the scores that have been given by the grading group, it is decided which of the contractors that go through to the interviews. Kashiwagi [6] uses the term *shortlisting* about this step. Van de Rijt & Santema [4] do not recommend shortlisting, but rather advice that all the contractors should normally go through to the interviews. It is important that the interviews are conducted with the contractor's key personnel who will actually do the work in the current project, such as project managers [4]. The interviews are recorded, transcribed and become part of the contract. The contractors are then graded, and based on the weighting criteria the best value contractor is selected. A *dominance check* is then performed, in which the accuracy of the information given by the contractor is assessed to ensure that the best value contractor has been selected [6].

3. The *Clarification phase* is perhaps the most important phase [4]. In this phase, the selected contractor is given time to clarify and elaborate their offer. However, no negotiations or additions to the offer are to take place in this phase. Furthermore, no 'real work' is to be done in this phase: The Clarification is rather a phase for defining the project to the largest possible degree, such that all the main aspects of the project have been addressed before the execution starts. The idea behind this model is to save transaction costs because the other bidders do not need to use resources in detailing the project. The Clarification phase should be led by the contractor. The presumption is that the contractor is the expert, and he should not be dictated or micromanaged by the project owner [4]. This phase typically lasts 4 to 6 weeks [4]. If the project owner is convinced that the selected contractor is indeed the contractor that provides the best value, the contract is signed at the end of this phase. The Clarification phase starts with a *kick-off meeting*. Here the contractor shall present his plans in detail to the project owner. A *risk management plan* should be formed, which describes all the risk factors in the projects and how they can be reduced. Furthermore, a *scope document* should be created, which describes which activities are part of the project and which activities that are not. To make the contractor's performance measurable, *Key Performance Indicators (KPIs)* should also be formed. These should be used to measure the contractor's performance in the Execution phase [4]. If the project is complex and involves several subcontractors, *elaboration of potential critical subcontractors* may be requested [16]. The *contractor* should also *be involved in framing of the contract*. However, this does not mean that the contractor writes the entire contract; but through interviews and statements made in the Clarification phase, the contractor will inevitably contribute to the content of the contract [12]. *Reassessment of interviews* may also be done to ensure that any concerns from these are addressed [16]. It should be made clear that the *project owner is financially responsible for all uncontrollable risk* [4]. This gives a larger incentive for the contractor to identify the risk factors that lie outside of his control, with accompanying plans on how to mitigate these risks. A *risk contingency fund* may be used to account for unforeseen circumstances. This is not part of the original BVP methodology but has been used in some Dutch projects [16]. The Clarification phase ends with an *award meeting*. At this stage, all risk factors and scope of the project should be solved, and the KPIs should be agreed. If the contractor and project owner are in agreement, the contract may be signed.

4. The *Execution phase* is the final phase of BVP. In this phase, the project is to be executed in accordance with what the project owner and the contractor have agreed upon in the Clarification phase. Both Kashiwagi [6] and van de Rijt & Santema [4] state that it is essential that both the project owner and the contractor stick to the BVP method in the Execution phase. The *weekly risk reporting* is important in this phase, in which the contractor keeps the project owner updated on the status of the project. Both positive and negative deviations in relation to the project plan should be reported, in addition to any changes in risks. This is a key part of securing transparency and protecting the project owner from poor performances from the contractor [4]. The contractor should include *performance measurements* in accordance with the KPIs as part of the weekly risk reporting [4]. A *directors reporting* may also be used. This is a report that is delivered to the project owner's management, such that the project's costs and time can be monitored [4].

4. Results and discussion

4.1. The use of BVP in practice

The use of BVP in the two Norwegian projects aligns with the theoretical approach identified in the literature. No major nonconformities to the theoretical model were discovered. A matrix of BVP elements and other elements that were identified in the literature is presented in Table 2, with indicators of the presence of such elements in the two cases. Both projects are still in the Execution phase. Procurement was done using an open tender procedure. Both projects have opted for the use of underlying standard design-build contract provisions, namely the Norwegian standard NS 8407.

Table 2 – Presence of BVP elements in the two cases

Elements from BVP		Flatåshallen project	Metrobuss project
1. Preparation phase			
Sponsor		X	X
Involvement of external BVP expert		X	X
Selection and education of core team		X	X
Pre-qualification of contractors		–	–
Use of all four phases		X	X
Training sessions for contractors		X	X
Core document		X	X
Open budget w/ceiling		X	X
2. Selection phase			
Award criteria in MEAT:	• Project capability	• 25 %	• 20 %
	• Risk assessment	• 15 %	• 20 %
	• Value added	• 10 %	• 15 %
	• Interviews	• 25 %	• 25 %
	• Price	• 25 %	• 20 %
Shortlisting		–	–
Two or more independent grading groups		–	–
Dominance check		X	X
3. Clarification phase			
Kick-off meeting		X	X
Risk management plan		X	X
Scope document		X	X
Elaboration of potential critical subcontractors		X	–
Reassessment of interviews		X	X
Key Performance Indicators (KPIs)		X	X
Award meeting		X	X
Contractor involved in framing of contract		X	X
Owner financially responsible for all uncontrollable risk		X	X
Risk contingency fund		–	X
4. Execution phase			
Weekly risk reporting		X	X
Performance measurements		X	X
Directors reporting		–	X

In both projects, all four phases have been used. Pre-qualification was not used in either of the projects. Furthermore, shortlisting was not used, such that all the bidders were given the opportunity to be interviewed. Two or more independent grading groups were not used. Elaboration of potential critical subcontractors was requested in the Flatåshallen project. This was not deemed necessary in the Metrobuss project, as there are few subcontractors in this project. Risk contingency fund was not used in the Flatåshallen project, due to small margin in the project budget. Directors reporting was not used in the Flatåshallen project, as the project owner is a one-time construction client.

4.2. The experiences with BVP

The general view of BVP is positive in both projects. The project owners and the contractors were mainly positive about the BVP method and philosophy. However, some challenges with the method have been identified. The positive experiences and challenges are presented in Table 3.

Table 3 – The experiences with BVP

Positive experiences	• Project cost predictability because of open budget with ceiling
	• Faster procurement phase for the project owner
	• The interviews are well suited to differentiate between contractors
	• Contractors are to a larger extent evaluated on their competence compared to traditional procurement methods
	• The Clarification phase provides foreseeability for the execution
Challenges	• The project owners and contractors are uncertain about the method
	• Uncertain whether time or costs have been saved in the procurement phase for the contractors
	• Legal challenges concerning public procurement law
	• Difficult to balance the line between clarification and negotiation in the Clarification phase
	• Lack of specific contract provisions for BVP projects represent a challenge in the Execution phase

In both projects, *project cost predictability because of the open budget with ceiling* was put forth as a positive element, especially from the project owners' point of view. Since the budget with ceiling is released up front as information to the vendors, the probable cost of the project is known at an early stage. Furthermore, the project owners pointed to a *faster procurement phase* since the tender documents need less detailed descriptions. The project owners also agreed that the *interviews were well suited to differentiate between the contractors*. There was a great difference in how the contractors performed on the interviews, and the project owners were very positive to using interviews as a means of differentiating between contractors. In addition, the *contractors are to a larger extent evaluated on their competence compared to traditional procurement methods*. The contractors express that this is a much-appreciated change to the usual tough price competition, which yields less room for their expertise. Furthermore, *the Clarification phase provides foreseeability for the execution*. The contractor gets to know the project better through this phase, and relationships to the project owners are formed.

Despite the many positive experiences, there are some challenges. The main challenge was that the *project owners and contractors are uncertain about the method*. Many of the offers from the contractors lacked the specificity and verifiability that is expected. Furthermore, the contractors perform poorly on the interviews in general. The uncertainty with the method was also challenging in the Clarification phase. The contractors had trouble leading this phase and trouble forming measurable KPIs. These challenges are probably caused by the contractors' lack of knowledge and experience with the method. Conversely, the contractors in both projects find that the project owners are having trouble 'letting go' of control in the Clarification and Execution phase. This corresponds to the observations made by Snippert et. al. [2], in that project owners frequently fall back on the traditional model of management, direction, and control, instead of leaving the technical decision making to the vendor. Thus, despite the presence of BVP elements, there is a gap between theoretical and practical application of the BVP *philosophy*. Furthermore, it is *uncertain whether time or costs have been saved in the procurement phase for the contractors*. Both contractors state that no costs or time has been saved in the procurement phase. Although BVP simplifies the procurement phase in that the contractors should only deliver 6 pages of documents, the price of the offer must still be calculated as usual, and the budget ceiling must be controlled. There are also some *legal challenges concerning public procurement law*. An interviewee expressed that it is challenging to subsequently reject a contractor who has been selected to the Clarification phase. At this stage, the contractor has put down a great deal of work and resources in the project, and would probably not give up without a fight. As such, a proper rejection in accordance with public procurement law would require thorough documentation from this phase. Furthermore, it is *difficult to balance the line between clarification and negotiation in the Clarification phase*. Although there should be no negotiation in this phase, the distinction is not always easy to draw. In addition, the *lack of specific contract provisions for BVP projects represents a challenge in the Execution phase*. Both projects use underlying standard contracts. These do not account for any special considerations that must be taken when using the BVP method, such as the weekly risk reporting. The standard contracts contain clauses that require the contractor to notify the project owner without undue delay if a change occurs. Thus, a challenge occurred when a change was reported in the weekly risk report, but not through the traditional system. This resulted in ambiguity about whether the change had been notified in time. The notification rules are preclusive, such that failure to notify in time results in a loss of the right to claim monetary compensation or extension in time limits. Since accountability and transparency are important principles in BVP, a need for clarification of the Execution phase through contract terms has been identified.

4.3. How should BVP be performed in future projects?

The interviewees were asked about success factors and pitfalls with the method to develop suggestions on how BVP should be performed in future projects. In addition, the interviewees were queried on what could have been done differently in the current and future projects. The interviewees agreed that the theoretical approach should be followed in future BVP projects. An overview of some key success factors and pitfalls that were found is presented in Table 4.

Table 4 – Success factors and pitfalls

Success factors	• Education in the BVP method for both the project owner and the contractor
	• Using an external BVP expert with thorough BVP knowledge and experience
	• Ability for the project owner to let go of control
	• Appropriate budget ceiling and time plan
	• Starting the BVP at an early enough stage of the project
Pitfalls	• Considering the method too easy
	• Using BVP for the wrong kind of project
	• Not being able to differentiate between the best contractor and the best seller in the Selection phase
	• Potential legal pitfalls with regards to public procurement legislation if the method is not followed

The predominant success factor that was identified is *education in the BVP method for both the project owner and the contractor*. This was put forth as a vital factor for succeeding with the BVP method and to creating ownership to the methodology. In this regard, the interviewees from the Metrobuss project also expressed that the internal training sessions on BVP should have been held earlier. The need for training in the Clarification and Execution phase is especially prevalent. *Using an external BVP expert with thorough BVP knowledge and experience* was also put forth as a success factor, especially by interviewees from the project owner's side. This was argued as important to implement the method correctly so that the method can work as proposed and legal problems are avoided. *Ability for the project owner to let go of control* was also mentioned as a success factor. The project owner has to be prepared to provide more information than usual and focus on facilitating an environment where the contractor can succeed. This has been identified as a common challenge in previous BVP projects [2,4]. Furthermore, the contractors emphasize that an *appropriate budget ceiling and time plan* is important. If these are set too low, there will be a constant race against the clock and to keep cost margins low. *Starting the BVP at an early enough stage* was stated as a success factor by interviewees from one of the contractors. To gain the benefits of the contractor's expertise, the contractors should be selected at a stage where they can exert real influence on the project. In the Flatåshallen project, applications for government permissions had been sent before the contractor was selected. As part of the applications, some main characteristics of the buildings were determined, such as building height. Although this saved some time for the project owner, since the processing of the applications could be done parallel to the procurement, the contractor expressed that this deprived them of freedom for how the project should be solved.

A common pitfall that was expressed is *considering the method too easy*. Although the BVP method focuses on the expertise of the contractor, it still demands thorough education and cannot be regarded as simply a 'procurement trick'. *Using BVP for the wrong kind of project* was also identified as a potential pitfall by the interviewees. If the method is used for projects where there is little freedom in choice of solution, the expertise of the contractor cannot be fully utilized. *Not being able to differentiate between the best contractor and the best seller in the Selection phase* was also mentioned by several interviewees. It is important to stick to the dominant information that is provided in the written documents and the interviews. Furthermore, an interviewee expressed that there are *potential legal pitfalls with regard to public procurement legislation if the method is not followed*. These pitfalls are related to the negotiation ban in open tender procedures, and the previously mentioned challenges that occur if the client wishes to reject a contractor in the Clarification phase and choose the second-best contractor.

5. Conclusion

The research questions addressed in this study are 1) how BVP was implemented in practice, 2) what the experiences with BVP are, and 3) how BVP should be performed in the future. The findings from the two cases indicate that BVP to a large extent has been implemented in accordance with the theoretical approach. Some minor deviations from the theoretical model have been identified, but these are related to BVP elements that are regarded as optional.

The experiences of project owners and contractors on BVP are mainly positive. The findings indicate that BVP is an effective and promising method for contractor selection and project management. The project owners can make a faster call for tenders, the Clarification phase provides foreseeability for the execution, and the budget ceiling yields project cost predictability. At the same time, the contractors find that they can utilize their expertise to a larger degree. However, some challenges were identified during the practice of the method. First, the contractors were inexperienced with the method, and their tender offers lack the specificity, measurability and verifiability that is expected in BVP. Second, the Clarification phase was characterized by traditional thinking due to the uncertainty on the method. Third, the legislation on public procurement represented a challenge, as the prohibition of negotiations in tender competitions is demanding to maintain in the Clarification phase. Fourth, the lack of specific contract provisions was challenging in the Execution phase.

The results indicate that future project owners will benefit from preparing the contractors better for the use of BVP. This may be done by facilitating training sessions for the contractors or by being persistent in using BVP in future projects. Through using BVP in future projects, both the project owners and contractors will gain experience with the method. Final conclusions can only be drawn after the projects have been finished, i.e. late 2018 and mid 2019.

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Trust: Work-related crime in the AEC-industry

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Abstract

In March 2014, the Norwegian newspaper Aftenposten released the first of 45 articles concerning the shadow economy of the Norwegian construction industry. It provided evidence that criminal actors continuously managed to infiltrate the construction supply chain. Therefore, this paper investigates the following research questions:

1) What are the main challenges regarding work-related crime?
2) How do contractors manage their reputation in the aftermath of work-related crime executed by subcontractors?

This exploratory study started with a literature review. It was followed by a case study based on a document study and 12 semi-structured in-depth interviews with representatives on strategic level. Some particularities of the AEC-industry makes it vulnerable to work-related crime. Complex supply chains, autonomous project managers measured on net profit, high weight on price etc. are examples of characteristics. The literature review reveals a knowledge gap regarding the current state when it comes to crime and crime-prevention within the industry. The findings indicate that the contractors managed the reputational challenges that emerged in the aftermath well on a strategical level. This was accomplished by clearly distancing themselves from the criminal actors within their projects, while still taking responsibility for correcting the situation. In this case study, the client even expressed increased trust in the major contractor after experiencing how the major contractor handled the situation. However such an approach might work the first or second time, but such an approach might work a couple of times, but with repeated infiltration of criminal actors the contractors have to do more than distancing themselves. Future research should focus on how contractors work to prevent work-related crime on the operational level.

Keywords: International construction issues; Work-related crime; Reputation Management; Trust

1. Introduction

Construction companies can be difficult to manage because of complex supply chains, autonomous project managers measured on net profit, high weight on price etc. Another particularity, namely the construction companies' vulnerability for work-related crime, does not receive sufficient attention in project management literature. In March 2014, the Norwegian newspaper Aftenposten released the first of 45 articles concerning the shadow economy of the Norwegian construction industry. This paper presents an insight into a major scandal that emerged from the Norwegian construction Industry, and how two involved contractors handled the aftermath.

The characteristics of the scandal revealed by the newspaper Aftenposten – hereby referred to as 'the case' – is outlined in the following. The case emerged during 2014 and consisted of a criminal network with a manager who systematically conducted tax-related crime and money laundering in the construction industry in the area of Oslo, Norway. The criminal network involved 37 subcontractors that consistently colluded with each other for almost a decade. The manager of the criminal network established- and ran the main company with the purpose of working as

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an intermediary between the major contractors and the sub-contractors. The main company contracted so-called mailbox companies to perform the job. The mailbox companies' only purpose was to bill the main company so it appeared that VAT was paid. The contracted mailbox company withdrew the money that came into their account, without paying VAT to the state. Then cash was returned to the main company, which in turn could pay salary to its unofficial employees. The manager alone embezzled 41 million NOK (app. €4.25mill) through such operations. Two well-known major contractors with a decent reputation, contractor A, and contractor B were affected since they had contracted sub-contractors related to the network.

The Police investigations revealed that out of the 37 subcontractors in the network, 34 were mailbox companies. Eight were created with the use of false identity and as many as 24 of them had no registered employees. In reality, the manager controlled all the 37 sub-contractors. However, in the public information, a variety of persons appeared as owners. For example, the spouse of the manager was CEO in one of the companies. In the other companies, the manager used stolen identities. The investigation revealed, among other things, that one person was behind four different identities figuring in four different companies over several years. The manager acquired false documentation, green cards and Norwegian bank accounts for his unofficial employees. The manager also acquired D-number for his employees, which is required for all foreigners working in Norway for less than 6 months. Overall, the manager of the network arranged all practicalities for those who worked for him, from picking them up at the airport to accommodating housing. The manager was eventually sentenced to prison for 5 years and received a claim for a deduction of 14 mill NOK from the state. Furthermore, he was denied the right to pursue independent business activity permanently.

The revelation proved the possibility to operate outside jurisdiction for quite a long time without being compromised by the Police or by the major contractors, for that sake. Those who contracted the company profited, as the criminals actually showed up on time, cost less than their legally operating competitors' cost and did a proper job (they never got complaints on the quality of their work). The Government lost VAT, so the society as a whole did not benefit from it. For the two major contractors that had contracted sub-contractors from the criminal network risked a damaged reputation when the newspaper Aftenposten revealed their involvement. Therefore, this paper investigates the following research questions:

1) What are the main challenges regarding work-related crime?
2) How do contractors manage their reputation in the aftermath of work-related crime executed by subcontractors?

This is an exploratory study starting with a literature review and followed by a case study consisting of a document study and 12 semi-structured in-depth interviews with representatives on a strategic level.

2. Methodology

This case study provides an empirical insight into the particularities of organized crime in construction and how the actors handled the aftermath. According to Yin interviews is one of the most important sources for acquiring knowledge and information in case studies [1]. Semi-structured interviews allows the interviewee to elaborate, even though the questions are set up in advance [2]. Furthermore, it permits asking relevant follow-up questions that may enrich the empirical data. The topic of the study is of such nature that it is a possibility that the answers the given were not completely honest, or not detailed enough. Therefore, the opportunity to ask follow-up questions was seen as a necessary advantage in this study. Furthermore, the interviews was conducted with four different groups, which creates data triangulation [1, 3]. Table 1 shows the different actors interviewed and number of interviews.

Table 1: Actors interviewed and number of interviews

Number of interviews	Actor
2	Contractor A (including CEO)
3	Contractor B (including CEO)
3	Involved clients
3	Non-involved clients
1	Investigator (police)

The interviews lasted between 20 and 45 minutes and were conducted with the use of a recorder. The use of a recorder was considered convenient in order to interact more freely with the interviewees. A possible source of error using a recorder is the possibility that the interviewees withhold information. All interviews were transcribed and the resume was sent to the interviewees for acceptance. Because of the nature of the study, it was considered necessary to keep the interviewees anonymous. This decision was made in order to extract the necessary data while avoiding potential negative consequences for the interviewees.

As a supplement to the interviews, the research consisted of a document study. The documents that were studied were both case-specific and non-case specific. The case papers consisted of a comprehensive description of the whole course of the case and the course of action, and thus a study of these has been indispensable in order to gain an underlying understanding. In the investigated case, information about the case primarily derived from case-specific documents (27,061 pages). The case-specific documents were supplemented with the experiences of the police investigator and Aftenposten (Norwegian newspaper) article series “The grey Economy”. Information obtained from Aftenposten has been checked against the criminal records. The Aftenposten paper edition contained 45 Articles from March 26, 2014 to April 7, 2015. The verdict is published without restriction in a public data base of LovData [4].

3. Theoretical framework

Many different improprieties may occur in the construction industry. Such improprieties range from operating in ‘grey areas’ to illegal practices [5, 6]. Engebø et al. revealed that surprisingly few contractors have ethical frameworks that differ between “grey areas” and illegal practices [7]. Le et al. offers a comprehensive review of corruption in construction [8]. Two prominent categories of corruption in construction is ‘fraud’ and ‘collusion’, with ‘fraud’ being misconduct in form of misinformation, deceit and theft, and ‘collusion’ being forms of secret agreements with a fraudulent or deceitful purpose [8]. A concern identified in the literature is the forging- and altering of invoices and money laundering [9-12]. Furthermore, such fraud can occur during every phase of a construction project [13]. For the Norwegian construction industry, problems related to work-related crime and counterfeit construction materials exist, but are not very much discussed [14-18]. In the case investigated in this study, both forging- and altering of invoices as well as money laundering was featured.

Jefferies et al. identified reputation as a critical success factor in winning project bids and that a trust-based owner-contractor relationship is a necessary contributor to successful projects [19]. Brønn and Ihlen argue that in order to understand reputation one must first understand the concepts of ‘identity’ and ‘image’[20]. Identity is an internally oriented term describing the profile- and values communicated by an organization, and employees' views on this [20]. ‘Identity’ is, according to Kvåle and Wæraas, ideas and concepts that give an understanding of reality [21]. When a business communicate with its surroundings, they communicate their identity to stakeholders [20]. Therefore, understanding their identity enables businesses to gain insight into how they are perceived by others. This impression forms the basis for the business's image. Image is "the immediate impression the environment has of the organization" [20].

To understand what the stakeholders really think about a business, one must look at reputation. In this context Freeman describes stakeholders as “a group or an individual who can work on or influenced by organizational actions” [22]. There is a lack of consensus in the definition of the term reputation, various academic disciplines such as Psychology, Economics, Strategy, Accounting, Marketing, Communication, organizational theory and sociology all have their own understanding of the term [23-25]. All businesses establish an identity and an image, but their reputation is something that is archived and earned [20]. Despite the variance regarding the concept of reputation, most agree that reputation is something that is constructed over time and affected by all actions of the company [26]. The purpose of upholding a respectable reputation is important for a widespread range of reasons. Regardless, the relative essence is that a respectable reputation affects the strategic position of the business [24]. The impressions the businesses provide over time creates “reputational capital” that can strengthen the competitiveness of the business over time [20]. Reputation is often determined by external factors outside the business’ control. It is therefore both challenging and time consuming to build reputation while at the same time avoiding risks that can lead to a negative effect on the reputation [20, 27]. Charles points out that one must both build and maintain relationships in order to achieve positive reputation: “A reputation that is positive, lasting and robust requires huge investment in building and maintain good relationships with the organization's environment” [23].

The reputation of a business may be greatly affected by media coverage [28]. According to Waldahl and Bryant and Oliver, the media's impact has been a key research area for media science [29] [30]. Today, the media is viewed as a powerful force. The term ‘agenda’ is relevant to the importance of media reputation. The leading hypothesis about the media’s ‘agenda function’ states that a subject given intensive media coverage causes the topic to be prioritized and discussed [31, 32]. In addition, the ‘agenda’ function of the media demonstrate how media influences the perceptions associated with the given subject. The subject is thus often being linked and associated with the businesses involved [32, 33]). This paper uses the following definition of reputation; “reputation is the surrounding’s perception of an organization over time" [20]. Thus, a good reputation is formed by a positive image over time. Furthermore, the perception of an organization changes for the better or the worse over time. Money laundering and altering of invoices are just some examples of activities that will alter it for the worse.

4. Result and discussion

In order to study how two Norwegian major contractors managed to safeguard their reputation in the aftermath of the discovery of tax crime and money laundering within their projects, this paper investigates the following research questions:

1) What are the main challenges regarding work-related crime?
2) How do contractors manage their reputation in the aftermath of work-related crime?

In the Norwegian construction industry, the term "unserious actor" is widely used to describe companies acting criminal. This term gives associations towards non-professionals, but not necessarily criminal actors. This may imply that parts of the industry do not fully grasp or understand the severity of organized crime and money laundering. Consequently, the actors do not enact the problem truly and the construction industry does not fully comprehend that criminals infiltrate the construction industry. Thus, creating favourable market-conditions in order for criminals to get a better foothold in the legitimate part of the construction. Industry. As long as the construction industry does not take the problem seriously, the criminals will succeed with work-related crime. Another explanation for the term "unserious actors" relates to the challenge of identifying a company as criminal when not convicted. It can take years from an initial claim regarding criminal actions until a final verdict. This might be problematic for public clients that operate under the Public Procurement Act that prevents them from excluding companies not yet convicted.

The media attention initiated- and enhanced the climate for dialogue between industry, law-enforcers, and authorities. Still, communication between the law-enforcers and the industry was identified as a challenging area. Some interviewees specified the challenge associated with ongoing investigations and confidential information, "It is a challenge that the authorities know many things that we do not know". Law-enforcers cannot inform the industry on their progress, which again leads the industry to believe that the police do not prioritise. Another major challenge is that the distribution of responsibilities is perceived to be unclear. It is a possibility that the contractors do not fulfil their supervisory duty accordingly; this is something the industry should improve. It is relatively evident that it exists a grey zone where criminal actors might strive within the industry's supervisory duty. Only clear and tidy communication between the industry and the official agencies will remove this grey zone.

One of the biggest challenges regarding organised crime is to uncover the existence and extent of the matter. The task of uncovering whether a sub-contractor operates within the regulations of the law is perceived to be demanding. Furthermore, it is proven to be challenging to get contractors in the industry to understand the seriousness of organised crime. Some interviewees remarked that it is demanding to distinguish the criminals from the law-abiding, in both the procurement phase and the construction phase. An important challenge that can prevent crime is to work for increased motivation to perform the supervisory duty more accurately. According to the police, a major challenge for the main contractors is to discover whether an invoice is fictitious or not. The same goes for uncovering false or stolen identity papers. In order to address future challenges, the findings suggest that clients should not transfer the responsibility for revealing work-related crime to the contractor. If irregularities occur on a project, the client will have responsibility independent of whether the major contractor knew about it or not. The client has responsibility for everything that is going on their projects according to Norwegian legislation.

The media exposed that major contractors used criminal actors on their projects at the expense of reputable actors. Thus, the reputable actors were excluded from the market because they were not able to compete on price. The extensive coverage of the emerged case placed the problem on the agenda for the construction industry. The relatively massive coverage facilitated further discussions within the construction industry. Furthermore, several public agencies aired their opinions. This corresponds well with the hypothesis of McCombs that intensive media coverage leads to increased prioritising [31, 32]. The media did not just put the issue on the agenda; they made lasting changes by making the industry more receptive to the Police and the authorities. This confirms the hypothesis on media influence the perceptions associated with the topic [33].

When asked how the case affected the reputation of contractor A and B, both the contractor- and client representatives agreed that this potentially affected the reputation. Eleven of the interviewees, from all segments, emphasized that decent reputation is important for the business. A client stated that it would weaken the reputation of the contractor if the contractor were "exposed to criminal acts repeatedly during a relatively short time". Furthermore, the majority of the clients stated that it was critical for the contractor to distance themselves from the criminals and the criminal actions. Regardless, the contractor still had to take responsibility- and demonstrate their ability to correct the situation. The interviewees were asked how they responded when it came to their knowledge that criminal actors operate in the construction industry. One of the clients believed that this case was a huge setback for the whole industry’s reputation. The emerging media attention affected how the entire construction industry appeared. The general view of the interviewees was that the most important measure for the construction industry actors in order to influence their reputation was to develop and educate their own employees, as they represent the company externally. Another aspect of good reputation was the ability to deliver good projects. A client representative stated that good reputation increases competitiveness over time. Furthermore, the interviewees considered reputation as a necessary ingredient in building an ethical and lawful culture.

Both the client and contractor representatives were asked about the importance of the media. The majority pointed out the media’s importance when it comes to setting work-related crime in the construction industry on the agenda. The newspaper articles on work-related crime in the construction industry were regarded as vital for understanding the extent of the crime. Both clients and contractor representatives agreed upon this. The media consequently put work-related crime on the agenda. One representative stated the following, "I want to say that this is a good example of the media as an effective arena for setting the agenda”. Furthermore, several interviewees emphasized that media put a focus on challenges not given sufficient attention within the construction industry. On the contrary, one client representative thought the media did not have enough knowledge about the conditions and the context of the industry in order to conduct such critical evaluations. Several interviewees emphasizes that the media attention made contractors more responsive to both the police and authorities. Both the police and the authorities had previously tried to set the agenda on work-related crime, but only after the emerging of the actual case, the industry took it seriously. In this particular case, the two contractors involved had a decent opportunity to manage how the media perceived them due to their information advantage. An advantage they successfully utilized. Smaller companies involved had much less impact than the major contractors did.

When the clients were asked how the contractors worked in order to manage their reputation, several characteristics emerged. The most fundamental principle of building a good reputation was perceived to be the ability to deliver good projects. That is, the contractors deliver the right quality, following the schedule, at the agreed price. Furthermore, the clients emphasized that some deviations occur in all projects, often in form of contractual deviations. In this specific case, the subcontractors did not pay taxes and fees in accordance with the Norwegian Tax Payment Act. Thus, the interviewees emphasized the importance of handling such contractual deviation in a professional and open manner, especially vis-à-vis the client. An interviewee from one of the contractors stressed the importance of handling such deviations in a professional matter to ensure future contractual agreements with the same client. As an interviewee stated, "If you deliver a good project for the client, the quality is good, keeping price and progress as well as all that we agreed on, then the customer often returns". In connection with the scandal, both contractors A and B emerged as good examples for others in the industry through being open in the media and taking responsibility for the circumstances on their projects. They showed corporate responsibility beyond minimum requirements set in laws- and regulation. Both realized quickly that their control routines were insufficient and thus gave clear signals that they would have to improve their current practice. Through their openness, the contractors made the impression that they did not hide information and that they were not deliberately involved in criminal matters.

Both contractors expressed the need for redeeming themselves after the discovery of criminal activities on their construction sites. From the clients’ perspective, it is important for contractors to deliver according to the contract and operate in accordance with laws and regulations. The consensus among clients was that the contractors’ openness and willingness to rectify the situation helped the contractors and mitigated the potential demise of reputation. Several of the client representatives stated that the handling of both contractors A and B in the aftermath was upright. One client thought that the case did not affect the reputation of contractors B at all. Some of the clients pointed out that the contractors effectively- and in a proactive matter affected others' perception by being transparent and honest. Both contractor A and B acted with haste to denounce their affiliation with the criminal actors when the scandal emerged in the media. Both remained clear that they did not want to associate with criminal actors. By doing so, they gave their clients a robust indication that such actors were not be allowed to enter their construction sites.

The media’s impact on the reputation of a contractor can be massive when revealing crime in their projects. In such cases, the interviewed contractors pointed out the importance of being transparent and presenting all the known facts involving criminal subcontractors. Simultaneously, both contractor A and B emphasized that their main motivation to counteract the criminal actors was that such actors challenged their business values. One of the contractors mentioned they felt a loss in prestige when media uncovered criminal actors on their construction site before they discovered it themselves.

Contractor A and B realized quickly that the criminals had to be excluded from the market. A major reason for the contractors to initiate such processes was due to the damage the scandal had on their reputation. Their immediate action is, in retrospect, viewed as an advantage. If they had hesitated, the industry might have changed their perception of them permanently to the worse. As seen in this case, being an already large and reputable contractor spawned yet another advantage as they had the resources to counteract. While the act of quickly distancing themselves from the case was a necessary act of damage control, it also poses one possible disadvantage. By quickly revealing their awareness, they also provided criminals a chance to alter their routines and adapt to the new market environment. Other contractors may learn from how contractor A and B handled the scandal and how they have worked for it not to happen again. The case study highlighted several countermeasures, summarized in table 2. The measures were implemented in order to safeguard the reputation of the contractors affected by the case.

Table 2: Measures used to safeguard reputation in the aftermath of unwanted incidents

Countermeasure	Description
Dissociate	Contractors dissociated themselves from the criminal activities by stating to both industry and media that such conduct was unacceptable on their construction projects, and that they worked vigorously on excluding such actors
Being a good example	Working on, preparing- and expanding their routines regarding prequalification of subcontractors, and pressed for more extensively use of prequalification system/ databases
Taking responsibility	Showing willingness to rectify the situation and taking responsibility. The contractors settled the case through improving the situation by improving their own routines
Continue to deliver good projects	The contractors continued their work on deliver good projects according to contractual obligations.
Professional management	Strong, transparent and open handling contributed to raise the contractors' reputation.
Redefining own requirements and systems	In order to prequalify its subcontractors, both contractors expanded their criteria's beyond minimum requirements by the law.

When it comes to the reputation of the main contractors, one of the clients argued that the case did not affect the reputation in the end. The client representatives agreed upon that the contractors' open attitude and willingness to improve their procedures and culture led to an overall increased positive reputation for the contractors. The results show that the serious work conducted by contractor A and B in the aftermath of the scandal in order to counter criminal actors, strengthened their prospect to mitigate future incidents both during contracting- and execution of projects

5. Conclusion

The main challenge for contractors regarding work-related crime is that a decent reputation is important for the business. If a contractor experiences criminal actors repeatedly during a relatively short time, this weakens the reputation. A (seemingly) decent reputation is necessary when building an ethical and lawful culture and it is necessary for a contractor when competing in the market. The single most important measure for the contractors' reputation is to deliver projects according to agreed price and quality within schedule while following the contract as well as legal jurisdictions. The findings suggest that the contractors perceived their reputation not weakened by their involvement with criminal actors. However, they felt the pride was compromised. The contractors stated that the main motivation to work against the criminal actors was that they challenged core values. It is essential to handle crime-related challenges in an open way to maintain a good reputation towards the client. Several measures were identified to safeguard the reputation of the contractors against work-related crime. Among other things, the contractors need to develop and educate their own employees, as they represent the company externally. The contractors must take responsibility for the situation by removing criminal actors and condemn illegal actions when revealed. The consensus among the interviewees was that the handling in the aftermath raised the reputation of both contractor A and B. The use of supplier databases for pre-qualification of sub-contractors became an important measure that both contractors now use in their work against criminal actors. Both developed their pre-qualification routines, well beyond the sole use of databases. This way, the contractors clearly stated their position and attitude in the industry. They take care of their reputation through an honest, open and professional approach.

Such an approach with clearly distancing themselves from the criminal actors, while still taking responsibility for correcting the situation, might work a couple of times. With the repeated infiltration of criminal actors during a relatively short time, the contractors have to do more than distancing themselves. They must actively prevent criminal actors from entering their projects. Furthermore, the fact that just some main contractors counteract criminal parties actively is not sufficient to solve the challenges of work-related crime in the construction industry. The rest of the construction industry and the relevant authorities also have to counteract work-related crime. Therefore, future research should focus on how contractors work to prevent work-related crime on the operational level.

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Challenges Faced by Stakeholders in the Road Construction Projects in the Gauteng Province of South Africa.

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Abstract

This study adopted a quantitative approach as the purpose was to investigate the challenges faced by stakeholders in the road construction projects in the Gauteng province of South Africa. This study adopted quantitative research and a well-structured questionnaire was distributed to different construction companies in Gauteng Province, which were registered with various approved councils construction professionals and contractors such as civil engineers, project managers, directors, quantity surveyors, construction managers and resident engineers. The questionnaires were sent via e-mails, some were delivered to the known construction companies by the researcher and some were distributed during site clarification meetings of contractors and consultant's bidders on Gauteng Department Roads and Transport tenders.75 Questionnaires were distributed and 50 came completed and eligible to use. Random sampling method was used to select the respondents in various organizations. Research findings revealed that Community unrest and land proclamation were the highest ranked factors that pose a major challenge in the road construction, time, financial constraints, cash flow, lack of proper panning, resources, delivery of material, plant and equipment, shortage of skilled labourers, lack of equipment, lack of materials, performance guarantees, project duration/period, cost overruns were the major challenges facing the stakeholders in roads construction projects in South Africa. In conclusion, proper planning, communication is vital to overcome the challenges and government at the other hand needs to partner with private companies in terms of transferring skills and upgrading the upcoming contractors by emerging them with sustainable, independent contractors. Therefore, any challenges found in roads construction might be eliminated in the future projects by lesson learned, by planning for the upcoming project properly and also by identifying possibility risk at the early stage of the project.

Keywords: challenges; construction industry; roads, south africa; stakeholder.

1. Introduction

The roads make our life easier in many ways as they link province to province even into other neighboring countries of South Africa [1]. In generally roads boost the country economy and simplify people's life. Furthermore it, creates employment, income for people and construction entails a complex interplay of client, consultants, contractors, tool, equipment's and materials [2]. Moreover, roads boost the economy in terms of transporting goods, mineral resources in mining, farmers, and improve the access of different facilities such as schools, hospitals, shopping centers, work places and recreation centers [3]. If roads are in good conditions, they also reduce travel times and people save fuels on their vehicles, reduce production costs for the ever-growing number of goods shipments [4]. The construction

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industry is the main distinct part that provides vital components as business, high recruitment of people and developing entrepreneurs for economy development [5].

However, the road construction has been facing some challenges. Road construction challenges are examined to be one of most repeatedly problem in the construction industry in South Africa. Most of the road construction challenges are continuous and there are recently new added challenges occurring in the industry due to new technology and other influences. There is a need to unlock or resolves these challenges within the industry [6]. "The challenges on roads construction are experienced on infrastructure which already incorporate, existing roads and the new infrastructure that is mushrooming which needs to take traffic into consideration [6]. Therefore it is vital to take roads challenges into consideration for better future modernizes quality roads in South Africa [7]. Many projects experience comprehensive challenges as results of exceeding initial scheduled time and cost estimates due to change of scope, procurement system. Stakeholders have positive and negative impact on road construction projects and hence, they contributes to the success or failure of the projects [8].

Department of Roads and Transport of Gauteng Provincial Government (GDRT) is obligated to road infrastructure network that interconnects the Gauteng provincial roads within the province and connects the Gauteng province with other provinces and countrywide. Hence the study will focus on the challenges faced by stakeholders in the road construction projects in the Gauteng Province of South Africa where most of the roads construction projects are taking place.

2. Overview of Gauteng Provincial road Network

In Gauteng there is a 5,846km provincial roads under the jurisdiction of the Gauteng Province Department of Roads and Transport (GPDRT), of which 4456km is pave and 1390km is unpaved. The Road Infrastructure Strategic Framework for South Africa (RISFSA) classification was used, for the development of the South African Road Classification and Access Management Manual (RCAM) classification system which deals with both rural and urban roads and also including the aspect of access management. Both RISFSA and RCAM are used in all Gauteng provincial roads. RCAM is a six-class rural and urban road classification system. Below, the table shows the road statistics of the paved and unpaved road [7].

Table 1: Network length by pavement type, 2015

Road type	Length (km)	Length (%)
Paved roads	4,456	76%
Unpaved roads	1,390	24%
Total	5,846	

Table 2 shows the road classification, the definitions of "Mobility" and "Access/Activity roads" have been extracted from the Technical Recommendations for Highways (TRH) 26 and are:

- A road with a 'Mobility' function is a type of road designed to protect and promote vehicle movement. Most of the activities allowed on 'Access/activity' roads are not permitted on mobility roads.
- A road with an 'Access/Activity' function is any lower class collector and local roads / streets where the access functions are greater in number [7].

Table 2: Road Classification (Mobility/Access)

CLASS	FUNCTION	DESCRIPTION
Class 1 Class 2 Class 3	Mobility	Principal arterial Major arterial Minor arterial
Class 4 Class 5	Access/activity	Collector street Local street
Class 6		Walkway

3. Construction industry

Construction is a billion dollar industry worldwide, much of which is linked to publicly financed projects [8]. However, cost and time escalation and poor quality are commonplace due to weak governance and endemic corruption [9]. Some causes of high rate of corruption in the construction industry are the fact that the construction industry has many close ties to the government and the industry involves complex, non-standard production processes that foster asymmetric information stocks between clients and providers [9]. Construction industry involves a large number of participants in a complex contractual structure that leads to a variety of psychological human behavior and attitude that promote corrupt activities [8]. Construction industry is always ranked as one of the most corrupt in the world due to large payments to gain or revise contracts and disobedience of regulations are common [10]. The impact of corruption not limited only to the payment of bribes however corruption extends to the construction of poor quality infrastructures with low economic returns and low funding for maintenance where great impact of corruption is felt [9]. Factors instrumental in corruption include the skills shortage within the construction industry, a perceived absence of deterrents and sanctions, and poor ethical standards [11].

4. Stakeholders in road construction projects

Stakeholders are Individuals and organizations that are actively involved in the project or whose interests may be affected as a result of project execution or project completion [12]. In construction Stakeholders can be a client, consultant, contractor, suppliers, community leaders, service providers [13]. Some researchers say stakeholders are internal and external, some say stakeholders are inside and outside and the others say stakeholders are primary and secondary [13]. Below is the figure identifying the potential stakeholders in construction industry adopted from [12]:

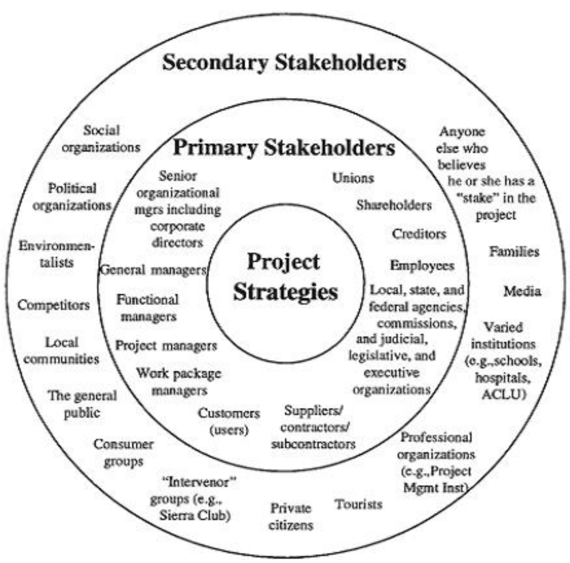

Figure 1: Potential Stakeholders for construction projects

In South Africa, community leaders and municipalities are very respective stakeholders in the project for political leaders to gain majority of votes in times of election however those leaders 80 % of them they are not technically qualified as they have occupied political posts; civil engineers at the national political level are rare however civil engineers can use political level to challenge the involvement in politics which can help them to gain more construction jobs and make good relationship with government in terms of tendering[14].

5. CHALLENGES FACING ROADS CONSTRUCTION PROJECTS

The South African roads construction faces challenges such as personnel on site, safety, time constraints and changing of scope of the work. Furthermore, there are indirect challenges that affect construction such as proclamation or landscaping issues which involves legal issues. Properties along the way where the road needs to be constructed, and the proclamation were not done properly therefore the legality process comes in if the owner of the property is not satisfied [15]. Sean Jones states that "The South African construction industry, is supposed to go through a high growth phase this year, owing to an increased number of construction projects, and a greater focus on housing projects and large-scale infrastructure projects, is facing severe problems regarding construction project delivery. These problems stem from a lack of capacity, skills shortage and quality standards"[16].

Other challenges are government regulations and policies which differ from one department to another. For instance, the roads construction can be done by department of roads and transport, and other government departments that need their protocol to be followed like department of labour, and the Contractor must obtain construction work permit approval to commence with construction work or activities [17]. Moreover, the department of water affairs requires the Contractor to obtain water license, the environment issues affects construction in a big way, such that the construction on wetlands or parklands, the Contractor must apply to the GDARD(Gauteng Department of Agricultural and Rural Development) which takes time for approval, some environmental issues are erosion, sedimentation and inclement weather. Failure to adhere with environmental regulations will results in a project being delayed or termination and contractor prevented to participate on future work opportunities or fines[17]. Failure to deliver road projects on time by the contractor displeases both clients and road users who expect to benefit from the completion of project on time. Moreover, projects delayed are very costly for contractor and different stakeholders of the projects [18]. Below are the challenges or constraints from contractor, consultant, client/general that may adversely affect the progress or failure to any road construction project in the Gauteng Province, South Africa [19]:

5.1. Challenges faced by stakeholders on roads construction projects

5.1.1. Design related problem

- Lack of detail specifications;
- Poor design reflection;
- unrealistic specification and even continuous changes of design by the client

Unprofessional design stops or delay the execution of project as the design needs to be reviewed amended and accepted or be approved for construction works. Once the errors are identified, works are temporary suspended until such errors are rectify. The errors normally occur in companies where selection process of vendors is compromised [20]. Issues arise from design which does not incorporate with the expertise of construction processes, rendering the design "difficult to construct" on site. Time, budget and quality are affected by design problems which impact risk on project. Normally in a project, design decision made by the consultant in the absence of the contractor and those decisions have constructability implications during the execution of the project [21].

5.1.2. Cost overruns

- These cost overruns have been attributed to design changes [22]. Design changes found to be most important source of construction wastage.
- In South Africa, most of overruns are caused by additional cost due to variation works, inflation or increase in the cost of construction materials, delay of drawings, contractor's bankruptcy or liquidation and others overruns [22].

5.1.3. Barriers to the uptake of new knowledge

Most road development projects in Africa are let on the basis of design specifications rather than performance specifications. Road pavement designs are prepared by consultants who must take responsibility for the performance of the road for a 15- or 20-year period [22 &23]. Consultants are not in a position to take any risk on the design and therefore tend to resort to 'tried and tested' solutions, even if these result in high construction costs. Practitioners in the road sector in most parts of Africa tend to lack access to new knowledge and awareness of new innovations [22 &23]. Some of the challenges that faces roads construction industry are little or no capacity at all level of government especially in municipalities and include the following [21; 22 &23]:

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- Lack of essential skills necessary for the management of projects,
- Undermining of engineering skills in municipalities;
- Poor project scoping and specification;
- Lack of knowledge relative to skills and resources required to implement projects;
- Contract awards based mostly on poorly defined tender processes,
- Lack of experienced employees capable of managing projects;
- Unnecessary time lags between tender submission and award.

5.2. Challenges faced by Contractors

Following are some of the challenges faced by the contractor in the roads projects

- Lack of proper planning

Any poor project planning to any project contract leads to project failure as a results of poor project management. It is also harm the nation as a whole in its infrastructural growth process. Lack of proper project control system, poor planning and poor work definition of scope lead to project failure or delayed [24].

- Inadequate Construction programme of works

Most of the contractors seem to fail to submit or produce construction programme of works to the engineer and client at early stage of the project. Submission of programme of works is one of the mandate or documentation required before commencement in order to meet the due completion date. Other contractors deliver or submit unrealistic programme of works to the engineer which delay the approval by the engineer as the programme needs to be adjusted [20].

- Resources

The contract/project managers failed to plan their resources in time, fail to scrutinize the work tasks or activities and their interactions on the project with the expected duration of the project [21]. Improper equipment selection & faulty equipment leads to delay of the project cause by time spent on repair [20].

- Poor performance by the contractors

Poor contractor's performance result in poor quality and low productivity [24].

- Performance guarantee
- Cash flow
- Delivery of materials, plant and equipment

Delivery of materials, supplies and equipment takes time than normal. Most of the Contractors do not have equipment and plant for their own; they depend on hiring of which sometimes they fail to get that equipment on time [25]. The delays on delivery of materials, plant and equipment cause by non-payment by the contractor.

- Time and Financial constraints.
- Absenteeism
- Tiredness

When contractors are under pressure, they engage workers to work overtime that leads to tiredness and no reasonable output can be achieved when body is tired and exhausted and it also cause poor quality of work done and accidents. Hiring of unskilled personnel hinder the execution of work on site as per specification and leads to mistakes during construction. More time spent on alterations and rework [26 &27].

- Legal provisions

Most of the contractors fail to comply with all applicable laws, regulations, statutory provisions and agreements. The engineer shall be provided with proof of compliance to the issues like water license if the contractor has obtained permission and permits for execution of works by the contractor from any Act of Parliament, Ordinance, Regulation or By-laws of local or other statutory authority [27 &28].

- Procurement method chosen
- Lack of Risk management

M1 Grayston Bridge in Gauteng, South Africa collapsed due to improper planning of risk. Risk information needs to be transmitted intra-organizationally hence the communication becomes an important aspect of risk management and risk identification [25,29&30]

- Existing services and land/properties proclamation

Another challenge related to design, the existing services and land proclamation seems to be forgotten always when the designs of projects are underway. The existing services and land proclamation become issue and delay the project during construction phase therefore these issues needs to be considered during planning stage [18;32&31].

- Traffic volume

According to Roads Asset Management System (RAMS), 12,468 million (approximately 12.5 billion) vehicle-kilometers are travelled each year on the GDRT (Gauteng Department of Roads and Transport) road network. Majority of traffic occurs on paved roads, where 76 % of the total network length carries 99% of the total traffic volumes on the Gauteng Province roads therefore the life cycle needs to be analyzed as it will place a high emphasis on the reservation of the paved road network [7&33].

6. Methodology

6.1. Research approach and design

This study adopted a quantitative approach as the purpose was to investigate the challenges faced by stakeholders in the road construction projects. Quantitative research is based on the measurement of quantity or amount. It is applicable to phenomena that can be expressed in terms of quantity. A well-structured questionnaire was distributed to different construction companies in Gauteng Province, amongst construction professionals such as civil engineers, project managers, directors, quantity surveyors, construction managers and resident engineers. The questionnaire were sent via e-mails, some were delivered to the known construction companies by the researcher and some were distributed during site clarification meetings of contractors and consultants bidders on Gauteng Department Roads and Transport roads tenders.75 Questionnaires were distributed and 50 came completed and eligible to use and reflects 67 % response rate. It was difficult to gather questionnaires as the professionals are always busy, some of them returned questionnaire after scheduled time, and others apologized of not sending the completed questionnaire back. The study was conducted from reliable scholarly sources such as articles, journals, books, publications, websites and site experience on the field.

6.2. 5- Point linkert scale

5- point linkert scale was adopted for the study which gave a wider range of possible scores and increase statistical analyses that are available to the researcher [24]. The first linkert scale read is on agreement form as follows:

1- Strongly Disagree (SD)
2- Disagree (D)
3- Neutral (N)
4- Agree (A)
5- Strongly Agree (SA)

The second linkert scale read is on likelihood as follows:

1- Extremely Unlikely (EU)
2- Unlikely (U)
3- Neutral (N)
4- Likely (L)
5- Extremely Likely (EL)

The 5 point scales were transformed to mean item score abbreviated as (MIS) for each of the challenges faced in the road construction projects, the mitigations taken and the impact of stakeholders in the roads construction projects evaluated by the different respondents within the roads construction industries[24].

6.3. Computation of the mean item score (mis)

The computation of the mean item score (MIS) was calculated from the total of all weighted responses and then relating it to the total responses on a particular aspect. The formula is used to rank the challenges facing roads construction projects based on frequency of occurrences as identified by participants. [12]

$$\textbf{MIS} = \frac{1n1 + 2n2 + 3n3 + 4n4 + 5n5}{\sum N}$$

Where;
n1 = number of respondents for strongly disagree
n2 = number of respondents for disagree
n3 = number of respondents for neutral
n4 = number of respondents for agree
n5 = number of respondents for strongly agree
N = Total number of respondents

7. Findings and Discussions

7.1. Challenges faced by contractors on roads construction industries

Table 3 reveals that community unrest/disruption was ranked the highest with (MIS=4.10; STD=1.093); Existing services and land / property proclamation was ranked second with (MIS=3.80; STD=1.050); time and financial constraints was ranked number third with (MIS =3.72; STD=1.05) followed by cash flow ranked fourth with the (MIS= 3.70, STD=0.91); Lack of proper planning ranked fifth with the (MIS = 3.64; 0.851); Cost overruns was ranked sixth with (MIS=3.52; STD=1.035); Resources in terms of staff/personnel was ranked seventh with (MIS=3.44;STD=1.072); Delivery of materials, plant were ranked eight with (MIS=3.44; STD=0.972);Lack of detail specification ranked nineth with (MIS=3.34; STD=1.272); Shortage of skilled workers was ranked tenth with (MIS=3.32; STD=1.291); Lack of equipment and materials was ranked eleventh with (MIS=3.28; STD=1.246); Performance guarantees was ranked twelve with (MIS=3.26; STD=1.291); Project duration corrupt officials was ranked thirteen and second last unrealistic construction programme was the second last factor with (MIS=3.02; STD=1.152) and poor performance by the contractor was ranked the last factor contributing to challenges faced by stakeholders with (MIS=2.90; STD=0.544).

Table 3. Respondents ‘response on challenges faced by the stakeholder in roads projects

CHALLENGES FACED BY THE CONTRACTOR IN ROADS CONSTRUCTION	MIS	STD. DEV	RANK
Community unrest/ disruption	4.10	1.093	1
Existing services and land/ properties proclamation	3.80	1.050	2
Time and financial constraints	3.72	1.051	3
Cash flow	3.70	0.909	4
Lack of proper planning	3.64	0.851	5
Cost overruns	3.52	1.035	6
Resources	3.44	1.072	7
Delivery of materials, plant & equipment	3.44	0.972	8
Lack of details specifications	3.34	1.272	9
Shortage of skills labourers	3.32	1.203	10
Lack of equipment and materials	3.28	1.246	11
Performance guarantees	3.26	1.291	12
Project duration/period	3.24	1.061	13
Corruption by officials	3.24	1.287	13
Unrealistic construction programme	3.02	1.152	14
Poor performance by the contractor	2.90	0.544	15

8. CONCLUSSION

Community unrest was the highest ranked factor which is a major concern to all stakeholder (client, consultants and contractors). Community unrest such as strikes, stoppage of project by business forums, councilors interruptions disrupt the project spending more time negotiations of the community grievances delay project and sometimes total abandonment of project sites is the biggest threat to road construction projects. Moreover, the existing services and land proclamation also pose a huge challenge to delivering a project on time, it needs to be taken into consideration during early stage of the project. However, the problems identified are somehow different from other countries, since most countries were complaining about poor performance of contractors, lack of equipment corruption which were ranked the highest. But in this study we saw community unrest being the highest followed by existing services and time of the project. Therefore, proper planning and good communication with the various communities and different department must take place especial during the preliminary stage, and transparence, honesty must be key to every individual who is involved in the project. Therefore, any challenges found in roads construction might be eliminated to the future projects by lesson learned, by planning for the upcoming project properly and also by identifying possibility risk at the early stage of the project.

9. Recommendations

The service providers hired (contractor and consultants) should be rated in term of their key performance indicators, every service providers and client should "know how" in every aspect of the project. Any contractors employed should be properly managed in terms of resources, skills, cash flow, availability of equipment and other related aspects. It is also important for both private companies and government to work together in terms of transferring the skills not only to the upcoming professionals but to the government officials whom most of them are political appointed without relevant skills.

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Determination of a classification tool for IFC data models based on a predefined classification system

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Abstract

Open BIM models are generally based on the ISO-generic IFC (Industry Foundation Classes) data model. These data models only allow limited interpretations and evaluations concerning specific guidelines or standards. This paper presents a classification process for IFC data models, which allows adapting them according to country-specific classification systems. Ensuring that the different elements in a data model are adequately classified is particularly important for cost estimation during the early stages of a project. The proposed process allows assigning the proper classification even when the quality of the model is limited. The main steps include: (1) Analysis and understanding of the IFC structure, as well as a country-specific classification system, (2) creation of a classification tool for a country-specific cost structure using an IFC model, (3) creation of rules for quality assurance as well as the development of quantities according to a country-specific guideline for the development of preliminary cost estimates. The classification process was tested using IFC data models from construction projects to fit the classification standard for Construction Cost Plan for Buildings (Baukostenplan Hochbau (eBKP-H) in Switzerland). In particular, the classification was made for the "Structural Work" group of the eBKP-H using Solibri Model Checker and MS Excel. Results show that the proposed classification process was able to improve the allocation of the different elements to their correct category, reduce the number of unclassified elements, and ultimately improve the quality of the information used to do cost estimates.

Keywords: Classification process; IFC; Classification tool, Building Information Modeling, Solibri Model Checker

1. Introduction

In the late 1980s, scientists from the construction industry began to ask themselves about the possibility of a higher data exchange model in the construction industry. This idea came based on what already happened in another field a few decades before. A data model that could not just be limited to its geometric description but includes semantics. Such models first appeared in the car industry in the 1970s and were initiated by the US Ministry of defense and the German car industry [1]. To develop this concept, the Industry Alliance for Interoperability (IAI) was founded in 1994 on the idea of improving interoperability of the construction industry with informatics. It was an initiative from Autodesk and was composed of twelve US companies. It was shortly after renamed International Alliance for Interoperability as it opened its door to any companies around the world. This industry consortium aimed to create an open and free standard, to improve interoperability in construction. This standard would not be based on any specific software and be free of accessibility. From this idea, the Industry Foundation Classes (IFC) was born. In 2005, the IAI was renamed BuildingSMART, and they continue supporting the development of IFC.

IFC is an open international standard for Building Information Model (BIM) data that are exchanged and shared among software applications used by the various participants in the construction or facility management sector. The

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standard includes definitions that cover data required for buildings over their life cycle. The first release of IFC came out in 1997 as IFC 1.0 and was then updated through the years, with the second addendum of IFC4, released in July 2016 [2]. Open BIM models are generally based on the ISO-generic IFC (Industry Foundation Classes) data model. Since IFC4 it is covered under ISO 16739:2013. It will soon be replaced by ISO/PRF 16739-1 (currently under development), which in addition to using the EXPRESS data specification language (a compact and well-suited data definition language that includes data validation rules within the data specification), it will include the XML Schema definition language (XSD). This format enables interoperability with XML tools, and it is suitable for exchanging partial building models; however, it is not very much used in practice because it creates large files for building models. In addition, the release of the new ISO will extend the scope to include data definitions for infrastructure assets over their life cycle as well [3].

1.1. Classification system

The eBKP-H (*Baukostenplan Hochbau*), German for cost plan for building construction (SN 506 511) [4] is a Swiss standard for classification of building elements. It came into effect in May 2009. Based on the experience made in the first years of utilization this cost plan was updated in 2012. Since then, it is commonly used in the Swiss construction industry. To put it in an international context, the eBKP-H is equivalent to the Construction Specifications Institute (CSI) and Construction Specifications Canada's (CSC) UniFormat, mostly used in North America to present cost estimates during the schematic design phase [5], but it addresses specific needs of the Swiss industry.

The Swiss Research Centre for Rationalization in Building and Civil Engineering (CRB) developed this standard based on the market needs and with the idea to elaborate a code based on the entire lifecycle of a project as described in the Swiss regulation SIA 112-Service Model [6] issued by the Swiss Society of Engineers and Architects (SIA, by its initials in German). The eBKP-H aims to cope with the ever-growing pressure of the construction industry concerning costs and requirements in increasingly complex projects. The classification of this standard allows construction companies and design firms to improve the quality of their cost estimates, getting them closer to actual construction costs. In addition, the precise definition of normalized terms, costs, and quantity units increases the transparency and the efficiency in the costs estimation.

According to [4], the eBKP-H has the following key functions:

- it can be used for classification of different building types
- it is a frequent basis for designers, contractors, and planners to present costs in a uniform manner
- it is independent of the function, size, complexity, structure, and construction of a building but also from the project phase
- it can be used for new constructions but also renovations or modification of existing buildings.

Although it can be used in later phases of a project (detailed design, tender, and construction), the eBKP-H is typically used during the conceptual phases. For later phases, the NPK (Normenpositionkatalog) [7], German for catalog of standard position, is preferred because it provides information that is more detailed (equivalent to the CSI and CSC's MasterFormat).

The eBKP-H is broken down into 14 groups, from Land to Value added tax (Table 1) and it consists of the following levels:

- Main Group: The main group contains different groups of elements. They are mainly used in strategic planning.
- Group of Elements: This level gathers different isolated elements together and is generally used in the preliminary study phase of a project. It can also be used in the previous phases if a differentiated elaboration is required.
- Element: The elements are defined according to their physical and functional characteristics. This level is mainly used in the project study phase but can also be used in the earlier phases.
- Sub-element: The fourth level is only used in the group of elements "H4 hospital installation", where a more detailed level is needed.

Table 1: Main groups included in the eBKP-H [4]

Main Groups					
A	–	Land	H	–	User-specific installations
B	–	Preparation work	I	–	Building surrounding areas
C	–	Structural work	J	–	Furnishing / Equipment / Decorations
D	–	Technical work	V	–	Planning cost
E	–	Outside walls / Cladding	W	–	Additional implementation cost
F	–	Roofing	Y	–	Provisions
G	–	Interior finishing	Z	–	Value Added Tax

The eBKP-H can also be used with a different degree of exactitude depending on the requirements of the SIA during the different phases of a project. It is organized as a hierarchy with up to four different levels. There are costs and normed references, which are assigned to every level. Each level allows assessing standard value for costs establishment, control and management at different stages of a project according to the SIA 112 phases [6]. The grade of detail increases with the level of the classification (from the main group to the sub-element). According to the required accuracy of a cost estimate, a different level of the eBKP-H classification should be used. Table 2 shows an example of the decomposition of group C (Structural Work) into its group elements and elements.

Table 2: Example of classification for structural work (main group) and corresponding group elements and elements [4]

Main Group	Group of Elements	Elements
C - Structural work	C1 - Foundation	C1.1 - Pipes and underground utilities
		C1.2 - Sealing and isolation
		C1.3 - Continuous footing
		C1.4 - Floor slab (nonbearing)
		C1.5 - Floor slab (bearing)
	C2 - Bearing wall	C2.1 - Wall (exterior)
		C2.2 - Wall (interior)
	C3 - Column	C3.1 - Colums (exterior)
		C3.2 - Colums (interior)
	C4 - Floor & roof	C4.1 - Slab
		C4.2 - Stairs, Ramp
		C4.3 - Balcony
		C4.4 - Roofing
	C5 - Other	C5.1 -
		C5.2 -

Every level has a specific code standard. It begins with the “Main Group” defined by a letter, then the Groups of Elements, Elements, and Sub-elements are named with numbers and separated by dots (there is no separation between the Main group’s letter and the first number). For example, *H4.3.2 Equipment for surgery* belongs to the sub-element level or *C2.2 Walls Inside* to the element level.

The use of rules applied to IFC data has been investigated (e.g., applications to construction safety, [8]). Current open BIM models only allow limited interpretations and evaluations concerning specific guidelines or standards. The goal of this work is to create a classification tool for IFC data model that will identify and classify building elements according to specific cost structure. For this study, the cost structure used was the one from Switzerland, the eBKP-H classification (*Baukostenplan Hochbau* – German for cost plan for building construction) [4]. Although there is a lot of work done regarding the estimate during the early phases of the quantities required for construction projects ([9], [10]), the extensive use of BIM allows quantifying the materials required quickly and reliably to develop cost estimates from an IFC file. To be able to create an accurate cost estimate, the different elements have to be properly classified. To create a reliable classification tool, the work will begin with a good understanding of the IFC data model and the eBKP-H classification. This will allow to see what are the possibilities with an IFC data model and then classify the elements correctly according to the chosen classification. The creation of the tool itself will be made on the software

Solibri Model Checker [11] which is mainly a model checking software, but it also has a good classification capacity. This tool will also be based on some *Excel* tables.

To verify the usability of the model before classifying it and, at the end of the process, to ensure the accuracy of the classification, quality assurance tests will be done.

2. Classification process

The proposed classification process is divided into four different parts (Figure 1). Each of these parts (i.e., processes) consist of the sub-processes described in the following paragraphs.

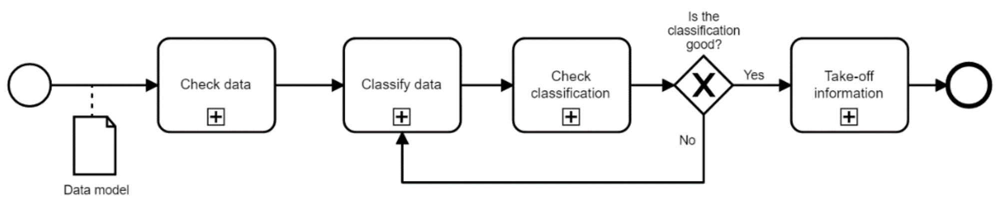


Figure 1: General classification process

2.1. Check data

The first step is to check the quality and accuracy of the IFC data model. Figure 2 shows the process for data verification. Once the format of the data is known, it is necessary to choose an appropriate software that will allow the reading and checking of data effectively. The checking rules must then be defined. It is essential that those rules are as accurate as possible to avoid unforeseen problems. Some points that can be verified are, for example, the consistency in the naming of the objects and the completeness of the model. It is also important to do a clash detection to be sure that there are no duplicated objects and objects overlapping with each other, which would lead to an overestimation of the quantities. It is useful at the end of the quality check to manually verify it through some random and independent checks. If the data model is considered good, this process is over. Otherwise, the model should be sent back to the person who created it with a list of issues to be addressed before the model can be used.

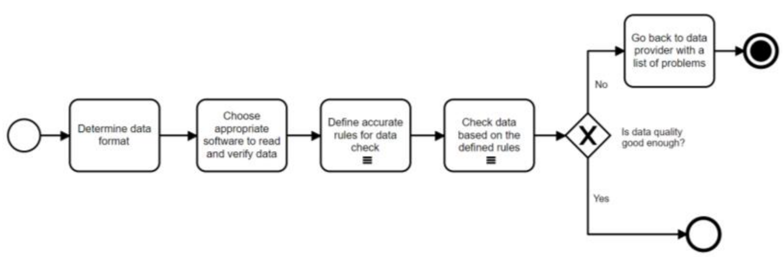
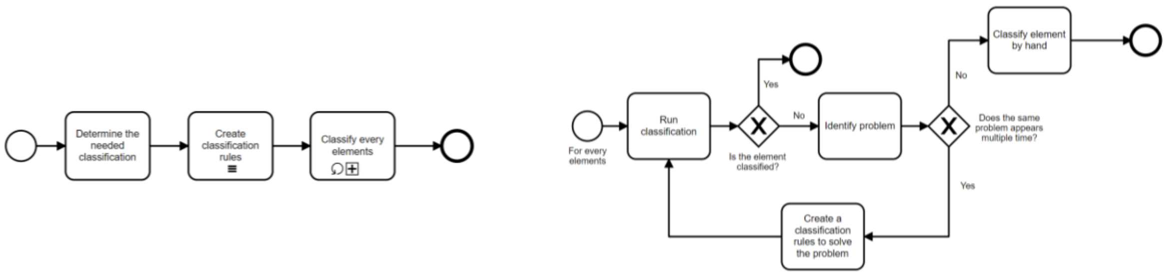


Figure 2. Sub-process for Check data

2.2. Classify data

Once the data is checked and it is verified that the model is usable, the data model can be classified according to a pre-defined classification. The first thing to do to classify data is to determine some rules to sort the data's elements accordingly. Those will mainly depend on the chosen classification (e.g., according to the eBKP classification or the CSI UniFormat). Figure 3 (a) shows the steps of the classification process.

The detailed process of the elements' classification is essentially done by the software itself. However, it is essential to fully understand how the classification works, as there will be some unclassified elements. For this reason, the classification of elements is also considered in the proposed classification process (Figure 3 (b)).



(a) (b)

Figure 3: Second sub-process of the general classification process: Classify data (a) and sub-process: classify every element (b)

Every element will first go through the previously defined classification rules. If the element is classified, the process is done. If it is not the case, there are two possibilities. If the same problem occurs several times a new classification rule must be defined, otherwise the element has to be classified individually by hand. The probability of having the same kind or type of object not allocated in a class can easily be checked after the first classification is done by checking all the unclassified elements. It is usually easy to verify if there is a recurrence. This process has to be repeated as long as all elements belonging to a category are not classified or have been classified in the wrong category.

2.3. Check classification

When all the elements are classified, a check on the quality of the classification should be made. This step could seem redundant as the elements are sorted according to rules that were defined for the classification, but it is an important part of the process as some problems can still exist. Figure 4 (a) shows the checking process.

The first thing to do is to determine some quality assurance rules. These rules will depend on the data which are classified and the expected quality of the classification. For example, for a quite large classification with few categories during the early phases of a construction project where everything is not yet precisely defined, high precision is not needed. On the other hand, when a model is defined in detail, the classification needs to be accurate to be useful.

(a) (b)

Figure 4: The two last sub-processes: (a) Check classification and (b) Take-off information

2.4. Take-off information

Finally, when the classification is done and the quality controlled. The output of the process needs to be determined and well presented. Figure 4 (b) shows the process to follow in order to obtain useful information. The first thing to do is to determine which quantities are needed. When they are determined, based on the software used, there can be different ways to get them. A convenient way to show data is to use Excel. If the same take-off is done multiple time, a template can be prepared to present the data.

3. Development of the Solibri/Excel tool

Based on the classification process described in the previous section, a classification tool has been developed. In this section, the specific characteristics of the eBKP-H classification and the IFC data model are used.

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3.1. Check data

The data model format is IFC, and the software used Solibri. The third step, Define accurate rules for data check, is certainly the most important part of this sub-process as the rules to check the model are chosen here. The first sets of rules are based on existing rules available in Solibri classified as Structural rules. The two existing ruleset are named: “BIM Validation – Structural” and “Intersections between Structural Components.”

Those rules were chosen based on the existing rulesets in Solibri for structural model verification, and the ones that seemed useful were selected. It is always possible to add some rules based on the need of a model or a classification. The new rules can be taken from the existing ones, or new ones can be created.

After the rules are chosen, the model is checked (Checking layout of Solibri). The outcome of this process is a list of issues. This list shows all the elements that didn’t follow one or more of the defined rules. There are different possible ways to deal with problems (elements not following the chosen rulesets). If the problem is of minor importance or if it does not influence the result of the classification, it can be ignored. If it does have an impact, the responsible person for this problem should be contacted and asked to make the necessary changes before the process can go further.

3.2. Classify data

The classification implemented in this study is the eBKP-H Swiss standard. For illustration purposes, only the main group *C – Structural work* was used. The rules created to classify the elements are based on this classification but also on the possibilities that the software Solibri offers. The rules are determined as follow. The first thing to do is to classify the elements according to their component, if they are defined as a wall, a slab, etc. An Excel tool is created to facilitate the creation of rules. A table is exported from the Solibri Rules, and thus new rules can easily be implemented in the excel file. Once all the rules are created, the excel table can be imported in the rules definition. To facilitate the definition of new rules, the column where the topic needs to be chosen from a list (*Classification name*, *Component* and every true/false property) must be filled by choosing from a defined list of possibilities. This needs to be done again to define the rules for the second level of the eBKP-H.

3.3. Check classification

When all the elements are classified, the model needs to be rechecked to make sure that the classification is good enough. This second verification follows the same process as the first checking process, except that the rules for this one are the ones for the verification of the classification. The rules for this verification are a lot more difficult to determine as it is harder to define quality sets for a classification. In addition, the aim of Solibri is not to check the quality of a classification. The first rule used ensures that there are elements in the classes (i.e., a rule will go through all the classes and make sure that at least one of them has an element on it). Another rule checks that the elements classified in the second level classification are also stored in the first level and that the group of elements is the same. Other rules could be defined and written in the rule manager window of Solibri and implemented as needed.

3.4. Take-off information

Finally, when the classification is done and verified, the information needs to be usable and easy to understand. Solibri already has a few built-in Excel templates for information take-off. One of them (Structural quantities) is used and further developed to export and present the information needed. Additional columns with the classes of every element are added to allow the calculation in Excel based on those rules. Any information, for example, volume or bottom area, can also be added to the exported information.

4. Implementation

The classification tool described in the previous section was implemented on an ongoing project consisting of a four-story office building located in an urban area with a plot size of 435 m^2 and a total building volume of approximately11,000 m^3.

4.1. Solibri Model Checker

The software used in this thesis is Solibri Model Checker or Solibri. It is mainly developed as a model checker that allows the visualization and combination of models from a different domain and to check the model based on predefined rules. Further, it provides a wealth of information that can be taken off (Solibri) [11].

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Both aspects will be used even if the predefined rules are only utilized to verify the quality of a model or a classification, and not to combine different models. The classification tool is critical and is the main tool that will be used.

4.2. Application to a model

To evaluate the process, an example of implementation is described and will be used to discuss the usability and the quality of the proposed classification process. This application is made using the software Solibri, and the IFC data model will be classified according to the main group C (Structural work) of the eBKP-H.

The verification of the data is done using two existing rulesets in Solibri: The two existing rulesets are named: “BIM Validation – Structural” and “Intersections between Structural Components.” The first one checks the validity of the model as a structural file. The second one verifies the intersections between overlapping components. Once the verification is done, Solibri output a list of problems with different levels of severity that need to be solved before going further into the process. It is important to know that Solibri does not allow modification or editing the model. Therefore, when errors are found, the model needs to be sent back to the person responsible for corrections before any classification can be done.

Now that the classification is determined, the classification rules can be defined (second step of the data classification process, Figure 3 (a)). These rules are based on the eBKP-H but also on the classifications’ possibilities implemented in Solibri.

4.3. Result and validation

A precise verification of the quality of the classification tool is difficult to perform as it is difficult to compare it with another classification. However, to evaluate the effectiveness of the developed process, a comparison between the first classification (original IFC data model) and the improved classification at the end of the process will allow to see the improvements, as well as what the verification and problem-solving process can provide. Table 3 shows the results of the first and final classification for the structural elements according to the eBKP-H level 1.

Table 3: Amount (volume) of concrete for eBKP-H elements from original IFC data model and after implementing the classification process

		Original	After classification
Main Group	Group of Elements	Volume (m^3)	Volume (m^3)
C - Struct. work	C1 - Foundation	-	1,120.66
	C2 - Bearing wall	1,563.53	1,563.53
	C3 - Column	565.00	22.54
	C4 - Floor & roof	3,448.16	2,358.31
	C5 - Other	-	-
	Unclasified	424.83	395.19
	eBKP-T		541.29

From this comparison, the main difference is for class C1. In the first classification, the class C1 has no quantities, while in the final classification volume and area are listed, which is a great improvement. Almost all the elements that went into the *C1 Foundation* class were before classified in the *C4 Bearing floors and roofing* class. Indeed, all the slabs of the lower level were first classified as normal slabs, when in fact they should have been classified as part of the foundation (i.e., slab on grade). The second class *C2 Bearing walls* remains the same; the walls are classified correctly from the beginning. The volume of the class *C3 Column* decreases in the final classification. The reason is that all the foundation pillars had been classified as columns; however, they should not be stored in this category or any other class of this catalog (including foundation), as they belong to the eBKP-T catalog [12] (cost plan for underground construction). Therefore, another category is created (eBKP-T) so that they are not assigned to the wrong category or accounted as unclassified. Going through the whole process of classification allowed to have a better classification with less unclassified elements but also an improved division in the classes.

5. Discussion

One of the most important lessons that result from this example is the great importance of a having a good model of the project. Indeed, if different types or the wrong components are used to define an element, a simple classification of this element is not possible. The quality of the model influences highly the outcome of the classification and the time needed to conduct the process. If the elements are not defined correctly in the model, additional rules need to be defined, and the effectiveness of the classification process is compromised.

A good verification of the classification is very important. First with some pre-defined rules that allow to verify the consistency of the classified elements, but also, visual verification of the different classes can easily expose some errors that can be resolved.

The software Solibri Model Checker that was used for the classification was very helpful and allows to classify efficiently but also to check the model and the classification very accurately and quickly. The proposed classification process improves the allocation of different elements to the correct category, reduce the number of unclassified elements by 7%, and since this is used to determine the cost of a project, to ultimately improve the quality of the cost estimates.

6. Conclusion and Outlook

The link between an IFC model and the classification of its elements is very important and could guarantee the development of quick and accurate cost estimations. Indeed, based on an IFC model, an estimated quantity necessary to estimate costs can be found in little time. However, to be able to have it as fast as possible, the quality of the model needs to be sufficient. To be able to draw an optimal IFC model, some knowledge of how the format is built and its properties are essential. These abilities will then allow automated classification of a building model. From a practical perspective, the time savings using the tool developed in this study to provide a robust classification of the different elements to be used as the bases of a cost estimation according to the eBKP are attractive to companies. Within a few minutes (depending on the size of the model) the elements and the important quantities (e.g., volume and area) of a model can be classified and outputted according to the eBKP classification (or another relevant classification system). Based on this and knowing the unit costs, cost estimation can be done. Even if improvements and new rules are needed, the process delivers good results very quickly. The time needed for a reliable estimation mainly depends on the quality of the model and its size. Future work on the classification tool could include other main groups from the eBKP-H and be expanded to other classification systems (e.g., eBKP-T [12] and NPK [7]). Also, the classification process could be improved by having a catalog with all eBKP classes could be included with the IFC specification to show how elements belonging to a specific class have to be drawn. This would help to have the model ready without any adjustment to be classified according to the desired classification.

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Collaboration Strategy for ODA Project using Social Network Analysis

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Abstract

Recently, Official Development Assistance (ODA) projects are increasing. Since ODA projects are financially stable, engineering companies planning to enter the international construction market need to make ODA projects as a first step. Engineering ODA project evaluates bidders by Quality Cost Based Selection (QCBS) method. Under the QCBS, companies make up for their lack of capacity through collaboration. Therefore, collaboration network information is required for winning. In this study, Social Network Analysis (SNA) is performed using the bidding information of socialbase, road, and water sector provided by World Bank (WB) for Vietnam ODA projects. The objectives of this study is to identify the network characteristics of the three sectors with the network shape and the density calculated through SNA, and to identify the main player by degree centrality and betweenness centrality, and to suggest an appropriate strategy. This is helpful information for decision makers when deciding whether to go overseas or not.

Keywords: Collaboration Strategy; International Engineering Project; Official Development Assistance (ODA); Social Network Analysis (SNA)

1. Introduction

1.1. Research Background

Recently, as the ODA project expands, the size of the multi-lateral development bank (MDB) procurement market is steadily expanding. Since ODA projects are financially stable, and track records can be accumulated through these projects, ODA projects will be the first step in entering the international construction market for engineering companies that have not yet entered [1,9]. Most of the ODA projects are evaluated by QCBS. In QCBS, generally, the company with the highest score by summing the technical score and the financial score as a ratio of 8: 2 is selected as the winning company. In addition to companies whose technical score is less than the standard score will be dropped, and the price score will be evaluated for the passed companies [7]. Therefore, engineering companies should have high technical competence for winning the ODA projects. For this reason, many companies tend to cooperate in a joint venture (JV) or consortium form to improve their competence. At the initial stage of bidding, collaboration network information should be considered for successful winning the ODA projects. The purpose of this study is to identify characteristics of network among bidding companies for each sector by using SNA. It is expected that the result of this study will support to set up the strategy about winning the ODA project by giving the network information such as network structure, main players in network.

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1.2. Research scope and process

WB manages the ODA project data in the form of an open database (Open DB) and discloses the bidding information of each projects. The bidding information includes the type of project, size, bidding company and collaboration information, technical and financial scores of each bidding company, bid price and so on. Focusing on bidding company and collaboration information, this study establishes a relationship network that links companies that have collaborated. Research process is followed as Fig. 1.

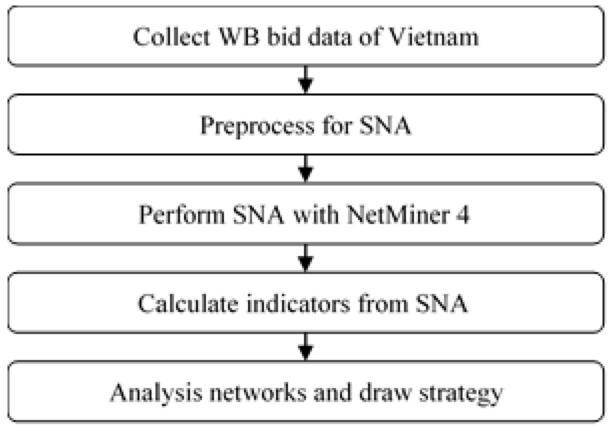

Fig. 1. Research process

First, the bid data provided by WB is collected. The collected bid data is the ODA project conducted in Vietnam where many ODA projects have been carried out, and the type of projects in the collected bid data are social base, road and water sector projects which have the highest proportion in overall ODA projects in Vietnam. In this study, bidding company and collaboration information for a total of 75 projects, 20 countries and 108 companies is used.

Second, the company name was set as the node and the relationship between the collaborating companies is created as an adjacent matrix by using the Matlab. And then, SNA is conducted by using NetMiner 4 and density and centrality are calculated. Finally, analyze the network of each sector and draw out the strategy based on the calculated indicators.

2. Research Methodology

2.1. Social Network Analysis

SNA is useful methodology for understanding the social phenomenon and social structure that Moreno started with the term “Sociometry” [5]. It has been used in not only social science research but also construction research such as communication management, stakeholder management and procurement management [2]. By using SNA, it is possible to analyze the network connecting the actor called node to the line called tie, and graphically shows the relationship or flow between the nodes by showing the given data with nodes and links. Through the structured network, various indicators can be used to identify key nodes, identify roles and positions of specific nodes, and evaluate the network itself.

2.2. Indicators of Social Network Analysis

There are various indicator to represent characteristic of network. In this study, density, degree centrality, and betweenness centrality are used to analyze the network.

Density (D) is the most widely used indicator for analyzing a networks and indicates how many nodes are connected on the network. It is possible to see how cohesively the network through density. Density is a value calculated for the entire network, and the equation is as follows [8].

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$$D = \frac{l}{n(n-1)/2} \quad (1)$$

where l = the number of existing ties and n = the number of existing nodes

Density has a value ranging from 0 to 1, and the closer to 1, the more cohesively. It is not an indicator of detailed information of the company level, but it can confirm the overall condition of the market or sector [3]. In this study, density of each sector of projects in Vietnam is investigated to see how cohesively network for each sector.

Degree centrality (C_D) is the sum of the number of nodes connected to one node, representing the extent to which a particular node is connected to other nodes. Since bigger network have larger value, sometimes the normalized value are adopted. There are two methods of normalization: i) dividing b N-1, the maximum degree centrality that can be calculated in the network, and ii) dividing by the sum of all Degree Centralities in the network, and the equation is as follows [4,6].

$$C_D(p_k) = \sum_{i=1}^{n} a(p_i, p_k) \quad (2)$$

where $a(p_i, p_k) = 1$ if and only if p_i and p_k are linked, otherwise 0

In the network of this study, the fact that a particular node is connected to many nodes means that the particular node is a main player that has collaborated with many companies. Therefore, the values of the top five companies with high degree centrality are identified. In the case of directional networks, in-degree and out-degree are calculated separately when calculating degree centrality, but the network used in this study is not considered since it is a non-directional network.

Betweenness centrality (C_B) is measured as the ratio of the path through a particular node among the shortest paths (i.e., geodesic) connecting any two nodes, and the equation is as follows [4].

$$C_B(p_k) = \sum_{i}^{n} \sum_{j}^{n} \frac{g_{ij}(p_k)}{g_{ij}}, i < j \quad (3)$$

where $g_{ij}(p_k) =$ the number of geodesics connecting p_i, p_j with passing p_k

Betweenness centrality represents a node acting as a mediator or broker, which means that there is a possibility to mediate the flow and exchange of information within the network [6]. Companies with high value of betweenness centrality can collaborate with many other companies by using their network. Therefore, if company A has a relationship with company B, which has high value of betweenness centrality, then A company can indirectly use the company B's network. In this study, companies with high betweenness centrality are identified and defined as target company for cooperating.

3. SNA Result

As previously mentioned this study analyses the collaboration network. Thus, nodes in the network stand for companies and each node is tied with the companies with which it has collaborated. The nodes with less than 4 ties were removed in the forthcoming figures since the purpose of the study is to identify the company with high centrality.

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3.1. Socialbase sector

Companies from 15 countries participated in the bid and the majority of them were Korean company except local companies. The network has 290 ties between 122 nodes and shows the density of 0.021 which is the least among the sectors. The entire network of socialbase sector is shown in the Fig. 2. forming a huge single network.

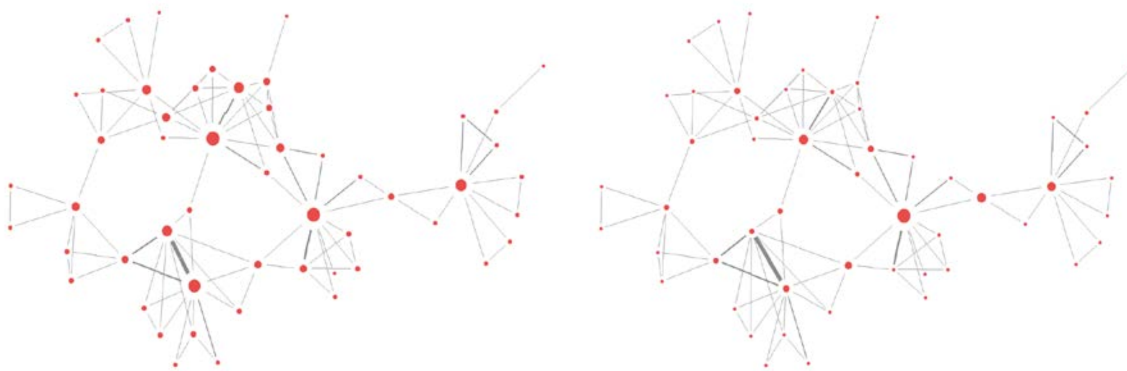

Fig. 2. Network of socialbase sector based on degree centrality (left), betweenness centrality (right)

Bigger node size represents higher Degree centrality on the left figure and higher betweenness centrality on the right, respectively. The analysis result shows that the value of highest degree centrality is 0.092 and the value of highest Betweenness centrality is 0.092 (Table. 1).

Table 1. Degree/Betweenness centrality of TOP 5 companies on socialbase sector

Degree Centrality		Betweenness Centrality	
K (KOR)	0.092	E (CAN)	0.092
E (CAN)	0.092	C (VNM)	0.059
R (NLD)	0.083	K (KOR)	0.058
Y (KOR)	0.075	Y (KOR)	0.053
J (KOR)	0.067	D1 (VNM)	0.040

Two Korean companies are included in the three companies which belongs to Top 5 in terms of both Degree centrality and Betweenness centrality. Moreover, the fact that other Korean companies are also in the high ranking implies that Korean companies are the main player of the socialbase sector.

3.2. Road sector

Companies from 16 countries participated in the bid in the road sector and the majority of them are American company except local companies. 242 ties between 90 nodes appeared in the network and the density is 0.031. The higher density of road sector is attributed to the fact that the number of tie is relatively larger to the number of node comparing to the socialbase sector. Hence, the network of the road sector is denser than that of the socialbase sector. Fig. 3., however, shows that the network forms the several clusters severed while there was single network in the socialbase sector.

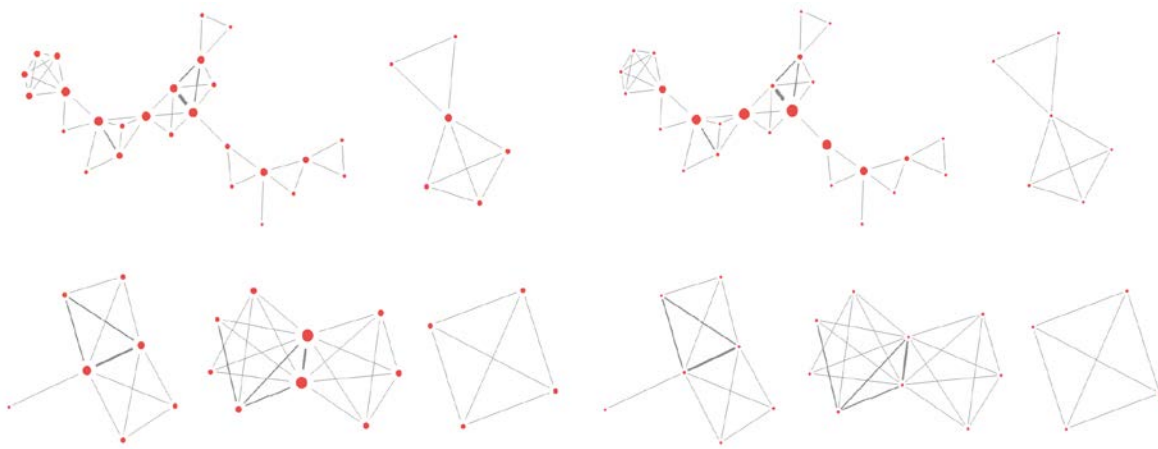

Fig. 3. Network of road sector based on degree centrality (left), betweenness centrality (right)

Those closed clusters indicate that the companies have formed the strong relationship which is exclusive to the outside. In this case it is recommended that a company takes a broker position linking clusters so that there would be higher possibility that the company enjoys takes advantage of both clusters.

The table below shows the highest Degree centrality of 0.091 and the highest Betweenness centrality of 0.042.

Table 2. Degree/Betweenness Centrality of TOP 5 Company on Road Sector

Degree Centrality		Betweenness Centrality	
C (USA)	0.091	S (AUS)	0.042
A (VNM)	0.091	T (VNM)	0.039
Y (KOR)	0.068	I (VNM)	0.033
T (VNM)	0.068	K (KOR)	0.032
S (AUS)	0.068	C (DNK)	0.027

Relatively low Betweenness centrality which stems from the network with the severed clusters make the market less profitable no matter which company collaborates in the road sector. Therefore, it is desirable to become the bridge linking the clusters.

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3.3. Water sector

Companies from 8 countries participated in the bid in the water sector and the majority of them are French company except local companies. The network has 226 ties between 93 nodes and the density is 0.05 which implies that the nodes are most concentrated. The dense network shown in Fig. 00 results in the high density even though the node-tie ratio in the water sector is lower than in the road sector.

Fig. 4. Network of water sector based on degree centrality (left), betweenness centrality (right)

Table 3. Degree/Betweenness Centrality of TOP 5 Company on Water Sector

Degree Centrality		Betweenness Centrality	
E (CAN)	0.099	E (CAN)	0.309
V1 (VNM)	0.077	D3 (VNM)	0.198
S (VNM)	0.077	V2 (VNM)	0.190
D2 (VNM)	0.077	S (KOR)	0.157
S (KOR)	0.066	R (NLD)	0.108

Betweenness centrality of water sector is far higher comparing to the other sectors. This is ascribed to the radial shape network in which companies are stretched from the main company in the center. As several companies might play a role as a broker it could bring the huge profit to collaborate with those companies.

4. Conclusion

In order to analyze the network of ODA engineering projects in Vietnam, this study used the bid information, which is provided by WB. With the information, companies that collaborated are represented in the form of network, calculating the density by sector and identifying main player companies. Among the three sectors, the socialbase sector has lowest density of 0.021, and the highest value of degree centrality and betweenness centrality are both 0.092. Since the density of the network is relatively low and the companies, except one company, do not have a high value of betweenness centrality, collaborating with a specific company is not a big benefit. In other words, there is no big difference in collaboration with any company except one. Road sector has a density of 0.031, the highest degree centrality is 0.091, and the highest degree of betweenness centrality is 0.042. Since there are several clusters forming a network, the betweenness centrality is low overall, so if it is possible to act as a broker connecting two or more clusters, it is a great benefit from a collaboration network. However, it is hard to be in the broker position from the beginning, it is necessary to take a chance by performing some projects. Water sector has the highest density of 0.05 and the highest degree centrality is 0.091. Because the network is radial shape, the highest betweenness centrality is 0.309, which is very high compared to other sectors. This means that there are several companies located in the broker position already, and if it is possible to collaborate with that companies, it will be of great benefit in a short period of time from a network.

Some limitations of this study are as follows. First, time is not taken into consideration. Even if the centrality is high, there may be companies that have bid in the past and are not currently. Second, it does not take into account the capabilities of companies. Even if the number of bids is large, it may not lead to win because of lack of competence.

In the future study, change of centrality of companies according to time will be analyzed and promising companies in recent years are derived. Also, technical score of each company will be analyzed, and then it is reflected on the network. Lastly, not only collaboration network but also competing network will be structured to analyze how strong the competition.

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Comparative analysis of regional construction labor cost variations via panel data modeling: the evidence of Mainland China

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Abstract

Labour cost estimation, control, and regulations are of great importance to the final success of construction project, and sustainable development of construction industry. Over the recent years, the affordability and availability of construction workforce, underpinned by rich labour resources across the Mainland China, has gradually become the history and exerted ripple effects on the construction manpower recruitment, cost management, and even industry development. However, little research has been found with focus on labour cost fluctuations at regional level in China. This study attempts to explore the major factors affecting regional construction labour cost variations over the past two decades, from 1995 to 2015. Panel data analysis, and time series econometric modelling, is thereby applied to identify critical determinants of construction labour cost fluctuations across three regions of different levels of economic development, i.e. underdeveloped west region, developing central region, and developed east region, within Mainland China's construction industry. Empirical results indicate that gross domestic product (GDP), unemployment rate, construction labour productivity, construction technical equipment ratio, and construction profit rate are five key factors determining the variations of unit labour cost in Mainland China's construction industry. GDP, construction labour productivity and unemployment rate are three common factors that affect regional construction labour cost; Besides, construction profit rate is found to be another dominant determinant of construction labour cost in west region, while construction technical equipment ratio acts as a significant but negative factor in central and east regions, with incremental effects towards construction unit labour cost from west region to central region, then east region. For the evolving construction market, these principal findings provide valuable insights for construction enterprises to formulate forward-looking market strategies, and for governments to fine tune economic policies.

Keywords: Construction labor cost; Critical determinant; Mainland China; Panel data analysis; Regional level.

1. Introduction

Labor cost estimation, control, and regulations are of great importance to the final success of construction project, and sustainable development of construction industry. Cheap construction manpower, provided by rich surplus labor force across Mainland China, has been regarded as a major superiority over other competitors in the past domestic market. With the fast-growing labor cost during recent years, prior labor advantage established has been largely diminished and become the history, exerting widespread effects towards construction manpower recruitment, cost management, and even industry development. Understanding potential reasons for labor cost variations in construction market can facilitate the responsive adjustments of market strategies of construction enterprise, and policy makings of related government, particularly during the period of construction boom. Therefore, labor cost variations need to be overall

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explored from the industry level, ensuring that construction labor cost can be better interpreted and reasonably tackled from various perspectives in a tight and competitive market. However, construction labor cost performance not only varies with time series but also changes greatly from region to region. The regional divergence can be partly attributed as a combined result of unbalanced distribution of industry demand, and uneven allocation of local resources. According to the market supply and demand, disparities exist within these two sides will probably lead to fluctuating labor cost and vice versa. Such differentials in construction labor market originate from the great variations in regional economic development, market structure, and industry performance. It is never an easy task to capture those complicated variations without a reliable and reasonable modelling and estimating approach.

2. Literature Review

2.1. Labor costs and changing trend-related research

Previous studies concerning labor cost within the construction industry mainly focused on the qualitative analysis to reveal underlying factors for its rapid rising trend over recent years. Wu et al. analyzed the major causes for fast-growing labor costs from the perspective of market supply and demand, and they found that the fundamental driving force comes from the need of economic growth with increasing levels of commodities price and inflation rate[1]. On the other hand, given that the poor image of construction industry characterized by harsh working conditions and long working hours, people who are willing to enter the industry become less if paid with uncompetitive wage or salaries[1]. The change of market supply and demand for construction workforce is thereby attributed to the rising labor cost, with additional burdens from raising price level and improving wage safeguard[2]. With closer linkages between construction industry development and economic performance, prevailing labor supplies hardly have the capabilities to meet soaring construction demands, hence labor shortage and skills crisis become the main barriers impeding the continuous growth of construction development, particularly during the booming periods of large-scale investment. An improved understanding of complex interplay of factors that shape the labor market will facilitate the identification of measures that can be taken to circumvent the negative effects[3]. The practicable strategies for resolving these problems are identified with assessing their effectiveness via questionnaires, and found that increasing labor wages, importing foreign workers and engaging employers to provide training are proved to deliver quick results[4], and other essential measures over the medium and long terms[5]. Confronted with the changing labor market and skills requirements, establishing a robust and reasonable model to estimate the occupational trends of labor supply and demand can facilitate effective construction manpower planning and responsive policy making, which is of immense importance to sustainable development of construction industry[6].

2.2. Multivariate time-series analysis of microeconomics and labor costs

For the estimation of labor supply and demand within the construction industry, five main classes of models including employer surveys, models of evolutionary comparison, mechanistic models, econometric modeling and cohort models[7], are assessed by examining their rationale, strengths and constraints, and compared with their reliability, capacity and other aspects, respectively[8]. A number of quantitative econometric modeling techniques including multiple regression[9], artificial neural networks (ANN)[10], vector error correction (VEC)[11, 12], autoregressive integrated moving average (ARIMA)[13] and gray model (GM)[14], have been utilized for simulation and prediction via a set of inter-related factors such as social variables, economic variables, industry variables and etc. Box-Jenkins approach called ARIMA model, is widely acknowledged as a benchmark technique for univariate method due to its structured modelling basis and acceptable forecasting performance[15]. However, univariate projection is not appropriate for estimating construction labor demand with limited data, similar with that of GM model[16], the forecasting accuracy will be largely disturbed if merely on the basis of its historic trend, particularly when encountering unforeseen or unexpected perturbation events. Therefore, multivariate time-series analysis such as VEC and multiple regression models perform more suitable and reliable for extensive simulation in the short-and-medium term[17]. Compared with multiple regression models[18], VEC modeling can better capture the causal relationship between construction manpower demand and associated factors covering the periods of ups and downs[12]. In the context of global economic turbulence, dummy variable is thereby introduced to propose a VEC-D modeling for diminishing external impacts towards accurate estimation[19]. On the other hand, considering the forecasting results, i.e. out-of-sample VEC modeling, are derived mainly depending on the simulation of in-sample fittings and the selection of variables. With this respect, some internal changes might be ignored or underestimated by subjective and patchy modelling for econometric forecasting, and a number of advanced models are thereby proposed by incorporating both qualitative and quantitative data to better manage and estimate the supply[20] and demand[21] of construction workforce, simulate their complex interplay via systematic dynamics (SD) modelling[22], thus improving the accuracy and consistency of forecasting based on construction projects[23]. Unfortunately, limited research has been devoted to constructing comprehensive models to capture both horizontal and longitudinal changes of construction labor market.

2.3. Panel data modelling for economic analysis

Panel data is an econometric approach for analyzing dynamic relationship due to its capability of coping with missing data and individual heterogeneity, and can automatically diminish the negative impacts of collinearity within various data sets that time series modeling and other regression techniques have no capabilities to avoid these aspects[24]. It has been widely applied in econometric analysis at firm[25], regional[26], or sectoral[27] levels within different time periods. Panel data consists of not only time series data but also cross section data, the introduction of cross section data increases the degrees of freedom and the reliability of statistics tests. Considering the sensitivity of time series modelling against external changes, construction sector and study period are thereby divided into several categories or stages[28], for better exploring causal relationship between construction activities and economic development within sub-study periods via Granger causality tests[29, 30]. Using the technique of panel data regression develops original error correction model (ECM) into a panel error correction model (P-ECM), which is able to outline the short-run dynamics associated with unexpected shocks of the economy, and account for the regional disparities based on long-run equilibrium function[31]. Besides, panel data modelling provides the possibility of generating more accurate estimations for regional variations and individual outcomes than time series projections.

Existing construction labour research mainly focuses on investigating the critical issues of labour market, for example, labour recruitment & employment[32], labour shortage & skills gaps[33], and labour supply & demand modelling[17, 34]. However, there have been few empirical studies concerning regional construction labour cost. Limited research has been conducted to explore the relationships between construction labour cost and its explanatory factors among different regions, albeit continuous upward trends of development across Mainland China in the last two decades. Furthermore, the implicit relationships between construction labour cost and its critical determinants might differ by time and region, because of many divergences exist in regions, industry development levels, and labour resources. This paper incorporates these diverse variations in regional construction market to examine construction labour cost across three regions, i.e. west region, central region, and east region, covering 31 provinces and cities in Mainland China, employing an advanced and combined econometric model, namely panel data analysis. The empirical results of this proposed method are compared for detailed discussions to identify regional differences of construction labour cost performance, for further references of construction enterprises and related policy makers.

3. Labor Cost Definition of Construction Industry

Labor cost refers to the total amount of money paid for employees who embark on construction industry during certain accounting period. As a main part of construction cost, labor cost consists of several components, i.e. wages and salaries, payroll taxes, and fringe benefits including paid leave, supplemental pay, insurance, retirement and savings, legally required benefits and so on. According to related on-site surveys, wages and salaries takes up over 80% of total cost of labor, sometimes even more than 90% among the site workers in China's construction industry. With this respect, labor compensation is universally interpreted as the total expenditure for construction worker, nearly equals to labor cost incurred during the construction process. Construction labor wage per hour worked (CLW) serves as a typical proxy for capturing the absolute variations of construction labor cost per unit time. But considering the extensive divergence of regional performance, project types and skill requirements of construction industry, it can hardly provide further detailed information, and diminish external disturbance that might not be conducive for comparative analysis.

Unit labor cost (ULC) is normally viewed as a broad measure of international price competitiveness. It is defined as the average cost of labor per unit of output produced, which can be expressed as the ratio of total labor compensation per hour worked to output per hour worked (labor productivity)[35]. This indicator is measured in percentage changes and indices[35]. ULC provides more specific information regarding the overall efficiency of construction labor input and final output per unit time. It can not only effectively capture the dynamic variations of labor cost, but also establish the implicit relationship with labor productivity for further implications. Meanwhile, selecting ULC as target variable can automatically diminish the external differences caused by different levels of regional development and construction industry performance, facilitating multi-dimensional comparative analysis among different regions.

4. Labor Cost Variations and Driving Factors

With ever-increasing labor cost across China's construction industry over recent years, it has become the main concern of construction industry development, and even drawn widespread public attention. Previous studies have been focused on investigating critical factors affecting labor costs within China's construction industry, especially during the stage of rapid growth, from the perspective of life cycle development. First, gross domestic product (GDP) is a monetary measure of the market value of all final goods and services produced in certain periods of time[36]. It is commonly used to determine economic performance of a whole country or region, and to make international or regional comparisons[36]. Economic performance directly determines the level of labor cost. Over the past three decades, the general income of employees in construction industry has largely improved due to consecutive economic growth. Besides, with more contributions of construction sector towards the national economy, stable economic growth promotes the rapid development of construction industry, and then drives the fast increase of labor cost in construction industry[2].

Second, as a pillar industry in national economy, the buoyant construction sector is also attributed to the huge amount of fixed asset investment. The sudden change of the amount of construction works created by central government broke original relative balance between market supply and demand, then impacted the level of labor remuneration. On the other hand, few newcomers have been attracted from labor pool due to the harsh working environment and unpromising career prospect. Although the income level for construction workers is much higher than before, most youngsters are prone to enter an industry with better working condition and higher social status instead. In terms of poor image of the construction industry, the decision makings for migrant workers might to some extent alter under different economic situations. In this sense, unemployment rate (UR) acts as a comprehensive indicator to describe the condition of economic landscape and job-seeking environment, which influences the direct recruitment of construction workers in terms of labor mobility, associated with labor cost management[37, 38].

Third, faced with rising labor cost and limited skilled labor in construction industry, labor substituted by construction plants and equipment is thereby regarded as an irresistible trend in terms of acute labor shortage across the industry. Applying construction plants and equipment into the construction process rather than recruiting expensive skilled labor would simultaneously attain multiple objectives including labor-saving, cost-saving, and time-saving in the long term. Therefore, contractors have to adjust their market strategies to manage construction activities in a flexible manner according to market change. In this context, technical equipment ratio (TER), the total value of construction machines per worker, perform as an overall indicator to reflect the application of plants and equipment in construction industry. Higher rate of construction technical equipment implies more utilization of modern machinery and equipment during the construction process, with less labor input thus higher labor productivity. Accordingly, the amount of labor inputs required is associated with the level of labor cost within construction industry. Besides, construction labor productivity (CLP) can be thereby enhanced with close linkages of labor skillfulness, and the uniqueness of craftsmanship, interpreted as the possibility of being replaced by technical plants and equipment[39-41]. Ultimately, both TER and CLP determine the level of construction labor cost via indirectly altering the amount of construction labor inputs.

Final, the internal proportion of construction cost varies with the development of construction industry, depicting different pictures at various stages. Therefore, how to balance the explicit relationship of each part of construction cost for the development need remains to be a critical issue for construction stakeholders to deal with. Some contractors attempt to bid for as many as construction projects to offset the decreasing profit rate in each working unit, while they do not fully understand the coming crisis and underlying message until the occurrence of labor shortage spread over the industry. Undoubtedly, maximizing the margin profits of construction project is the first thing that construction manager cares about. Once construction profit rate (PROF) is disturbed by external impacts, the responsive adjustments will be accordingly made to ensure the relative optimization for profit making. Increasing construction labor cost is bound to affect the space of profit gains, but how to tackle with this pressure based on corresponding strategies becomes quite important concerning whether both construction stakeholders and site workers can achieve the win-win situation.

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5. Regional Labor Cost Data and Analysis

5.1. Data source

According to literature review above, potential factors affecting labour cost in construction industry including GDP, unemployment rate (UR), construction labour productivity (CLP), technical equipment ratio (TER), and construction profit rate (PROF) are therefore chosen for further investigation with labour cost variations across construction industry. The annual data of these indicators can be obtained from National Statistics Yearbooks over the past two decades, i.e. from 1996 to 2016, covering 31 provinces or cities in Mainland China[42]. For regional division, 31 provinces and municipalities of Mainland China are categorized into undeveloped west region, developing central region, and developed east region, according to the administrative layout. West region includes 12 places, that is, Sichuan, Chongqing, Guizhou, Yun'nan, Shanxi, Guangxi, Inner Mongolia, Gansu, Ningxia, Xinjiang, Qinghai, and Tibet. Central region consists of 6 provinces, i.e. Hubei, Henan, Hunan, Anhui, Shanxi, and Jiangxi. East region incorporates mostly the coastal area, such as Hainan, Guangdong, Fujian, Zhejiang, Jiangsu, Shanghai, Shandong, Hebei, Tianjin, Beijing, Liaoning, Jilin, and Harbin.

5.2. Panel data analysis, tool, assumptions

Panel data analysis is used to model regional phenomena that other regional science methods are unable to handle, such as time dependent relationships among socio-economic variables. Apart from simply the time-series or cross-section regression, panel data modelling covers both horizontal and longitudinal dimension for overall examination. Besides, such models are often used to forecast or predict values of their dependent variables under various conditions. The basic model is the standard form of panel data analysis:

$$Y_{it} = \alpha_i + \beta * X_{it} + \mu_{it} \quad (i = 1, \ldots, N; t = 1, \ldots, T) \qquad (1)$$

$$Y_{it} = \alpha_i + \beta * X_{it} + \delta_{it} + \lambda_i \quad (i = 1, \ldots, N; t = 1, \ldots T) \quad (2)$$

Where Y is the dependent variable, the X_{it} are the independent or explanatory variables, subscript i represents the cross-section dimension, whereas t denotes the time-series dimension. Besides, the unobserved effects μ_{it} are captured including period individual-invariant effects λ_t and individual time-varying effects δ_{it}, characterized by structural parameter β and incidental parameter μ_{it}.

The effects of unobserved heterogeneity can either be assumed as random variables, referred to as the random effects model, or as the fixed parameters, referred to as the fixed effects model, or a mixture of both as the mixed effects model[24]. The advantages of random effects (RE) specification are that it allows the derivation of efficient estimators that make use of both within and between group variation and the estimation of the impact of time-invariant variables, based on the assumption of the effects uncorrelated with X_{it}. Meanwhile, the advantages of fixed-effect model allow the individual-and/or time specific effects to be correlated with explanatory variables, supported by limited coefficients without time-invariant ones[24]. RE specification and FE specification are mutually complementary patterns. To choose between two specifications, undertaking the Hausman test to determine RE versus FE pattern is an essential step before the modelling. Based on these criteria, panel data analysis is thereby conducted, model is initially specified by inputting all the listed variables, and results of Hausman test provide solid evidence for the selection of RE versus FE pattern, and statistical details are shown in the following tables below.

5.3. Model specification

The model specification is divided into several steps before conducting the panel data analysis. First, target variables and explanatory variables need to be determined respectively, and then the effects of modelling should be fixed via the Hausman test, whether the fixed effects or the random effects. Ultimately, the pattern of econometric modelling is therefore defined to see whether the likelihood ratio, i.e. F test, can be passed or not. For this modelling, panel data covers 31 provincial regions in Mainland China over past two decades from 1995 to 2015, during when experiencing the Asian Financial Turmoil, SARS, and the Global Mortgage Storm in 1997, 2003 and 2008, respectively. As is shown in Figure 1, the study period is accordingly divided into three stages according to the turning points and time spots of great events: 1995 - 2003 (Stage 1), 2004 - 2009 (Stage 2), and 2010 - 2015 (Stage 3). Detailed discussion will be then conducted from different stages, to obtain the reasonable and feasible findings.

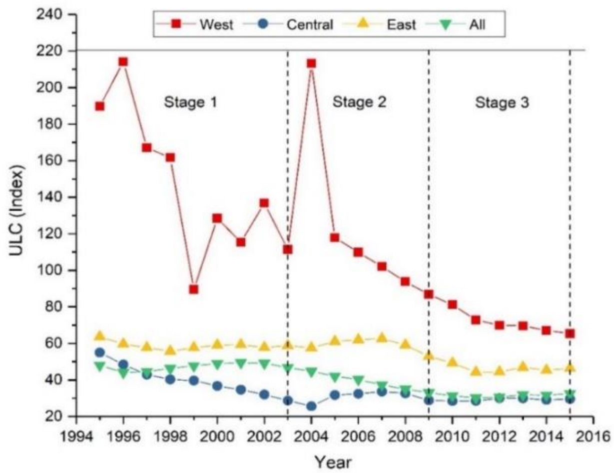

Figure 1 Regional Unit Labor Cost in China's Construction Industry (1995-2015)

6. Results and Discussions

According to the statistical tests of panel data analysis, established econometric models fit regional data well, and the adjusted R^2 shows a better fit for central and east regions, rather than west region, very close with the R^2 of all regions as a baseline. Besides, results of the Hausman Test suggest the fixed-effect model to be more appropriate than the random-effect model in representing the following cases (P-value less than 1%). Little autocorrelation problem for this panel is found according to Durbin-Watson statistics. GDP, CLP, and UR are found to be three common determinants of unit labor cost across various regions in Mainland China during entire study period. Positive coefficient of GDP is the biggest in west region, and gradually decreases from central region to east region, while the opposite condition for negative coefficients of CLP of these regions. Further, UR is positively associated with unit labor cost in both west and east regions, while negatively correlated with that in central region. The existing differences might be an overall result of diverse construction workforce strategies for meeting regional construction demands at different stages. This can be also evidenced by the significant coefficients of TER in central and east regions, which could indicate the application of construction plants and equipment in real practice, further reflect the reliance upon construction manpower.

Table 1 Panel Data Regression Analysis: Determinants of Unit Labor Cost in China's Construction Industry (1995 - 2015)

Independent Variables / Region	All Region	West Region	Central Region	East Region
GDP	0.001225[a]	0.00425[b]	0.000409[b]	0.000265[a]
CLP	-0.000557[a]	-0.001077[a]	-0.000232[a]	-0.000178[a]
TER	-0.001067[b]	-0.000641	-0.000592[b]	-0.000823[a]
PROF	-5.498919[b]	-8.795619	-0.409531	-1.367159
UR	17.55567[a]	26.43122[a]	-8.129785[a]	6.288969[a]
Constant	36.84578[b]	39.67743	71.09039[a]	49.39359[a]
F-statistics	26.14	16.668	65.602	245.631
DW statistics	0.77	0.851	0.616	0.553
Adjusted R-squared	0.58	0.51	0.837	0.939

Note: DW = Durbin-Watson statistics.
[a] Denotes significance at 1% level.
[b] Denotes significance at 5% level.
[c] Denotes significance at 10% level.

6.1. West region

Coefficients of GDP, CLP, and UR are statistically significant. Owing to the distinctive contributions from construction sector towards economic performance, the buoyant regional GDP promotes the incremental growth of construction labour cost, associated with the rising living standard. However, regional construction development in west region

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shows more reliance upon cheap construction workforce, whereas surplus labour force in undeveloped area is relatively sufficient in contrast with other areas. Although the employment-generation potential of construction industry has been effectively utilized particularly during the economic recession[43], the labour-intensive pattern of construction activity hinders efforts towards the improvement of construction labour productivity, also the rationalization of construction labour cost. To obtain as much as profit gains, contractors are inclined to reduce budget for construction manpower in early times, even delay payoffs to relieve the pressure of cash flow for cost management. All of these can be partly attributed to the low social status of construction workers themselves, and few barriers to entry into the industry[44], especially when labour supply exceeds industry demand. Thus, regional construction profit gains are at the sacrifice of unit labour cost within a long period of time, making it hard return to a favorable level until the outbreak of labour shortage across the industry. Under this circumstance, construction profit rate will be largely affected in a tight construction labour market, previous pattern for profit gains depending on low labour cost might not be applicable to prevailing market competition in new period. Besides, the insecure employment, and negative aspects of working conditions largely influence the attractiveness of construction industry[45]. Thus, construction contractors often have to pay disproportionally high wages in order to attract adequate numbers of workers, sometimes relying on untrained and little experienced workers, despite continued efforts to develop a core of local workers[46]. Moreover, the inadequacy of training facilities and programs has resulted in an acute shortage of skilled personnel. The development and proper deployment of a well-trained and competent workforce is quite important for the well-being of construction industry, particularly for a pillar sector in national economy.

Table 2 Panel Data Regression Analysis: Determinants of Unit Labor Cost in West Region

West Region	1995 - 2015	1995 - 2003	2004 - 2009	2010 - 2015
GDP	0.00425[b]	0.007499	0.034162	-0.000157
CLP	-0.001077[a]	-0.000712	-0.00276	-0.0000049
TER	-0.000641	-0.002823[b]	-0.0000108	0.000481
PROF	-8.795619	-14.07469[a]	-61.49385[c]	4.726488[b]
UR	26.43122[a]	15.60413[a]	153.0494	22.93482[a]
Constant	39.67743	88.52963[a]	-399.2181	-30.16263
Adjusted R^2	0.51	0.95	0.45	0.964

[a] Denotes significance at 1% level.
[b] Denotes significance at 5% level.
[c] Denotes significance at 10% level.

6.2. Central region

Unlike considerable fluctuations of construction labour cost in west region, labour cost performance in central region is much smoother with cyclic characteristics. Its turning points are easily captured in 2004 and 2009, respectively. The instability of construction labour cost is recognized as the result of fluctuations in the demand for investment, which usually gives a strong impetus to the development of construction industry[47]. Construction is regarded as an important tool in government's management for regulating the economy, much more knowledge is required about the way that industry works especially as a major participant[48]. Apart from those significant coefficients in west region, TER is identified to be negatively associated with ULC. In some regional centres, governments have used control over a certain segment of construction demands to promote the widespread adoption of new technology, aimed at reducing the reliance on labour inputs[49]. In addition, UR is negatively correlated with ULC in the early stage, and then turns into positive relationship later. Considering that central region merely includes six provinces, construction industry performance in regional economy might be not so prominent compared with other places in developed area. The industry is generally operating below the capacity, and construction firms would take responsive measures to increase labour productivity. Meanwhile, there exist some mismatches between the levels of construction labour cost and construction development. This implies the urgent need to raise labour wage for attracting additional construction workforce, during when the industry still has the capability of meeting growing construction demands, and resolving the issue of social employment[50]. As a labour-intensive sector, construction industry has absorbed massive surplus labour force not only from labour pool but also other related industries to satisfy the soaring needs, making the industry even more fragmented. With less available skilled labour in the construction market, plus limited new blood in young generation, labour substitution by construction technical plants and equipment will be an inevitable trend that must be reasonably considered and carefully treated, particularly during the successive construction booms. Otherwise, the negative effects are to emerge soon once the balance of market supply and demand is broken, due to external impacts

 DOI 10.3311/CCC2018-049

of international events or national policies.

Table 3 Panel Data Regression Analysis: Determinants of Unit Labor Cost in Central Region

Central Region	1995 - 2015	1995 - 2003	2004 - 2009	2010 – 2015
GDP	0.000409[b]	-0.001589	-0.000559	0.0000882
CLP	-0.000232[a]	-0.001036[c]	0.00042	0.0000276
TER	-0.000592[b]	-0.000261	-0.000899	0.0000644
PROF	-0.409531	0.167358	1.111548	2.355927[a]
UR	-8.129785[a]	-10.57576[a]	12.73308	0.226393
Constant	71.09039[a]	92.4512[a]	-17.56982	19.56229[a]
Adjusted R^2	0.837	0.87	0.879	0.985

[a] Denotes significance at 1% level.
[b] Denotes significance at 5% level.
[c] Denotes significance at 10% level.

6.3. East region

Similar with the baseline trend of all regions, all explanatory variables including GDP, CLP, TER, and UR, except for PROF, are significantly correlated to construction labour cost in east region. However, the big differences lie in less dependence on cheap unskilled labour, and more reliance on technical plants and equipment, depicted in latter two stages with clear features. The dependence on causal labour hampers the creation of a pool of experienced workers and introduction of new techniques, then total investment in plant and equipment. Coupled with the uncertainty about the nature and size of construction workload, this has reinforced the unwillingness of contractors to acquire technical plant and equipment. Meanwhile, it is closely related to the exact stage that regional industry development lies in. No matter from the industry structure and industry pattern, east region is superior to other two regions in Mainland China. As the leadership of national economy and construction industry performance, regional construction development in east region has been seeking shifts from labour-intensive pattern towards technical-intensive pattern, via seizing the transition opportunities accompanied with the rapid development of real estate industry in 2003, and initiation of Four Trillion Fiscal Stimulus Package in 2009. From a holistic view, construction labour cost in east region stays at a moderate level, which is less subjected to the external shocks compared with west and central regions. Although there remain some slight ups and downs, regional construction labour cost has entered into a mature development process that is able to adapt to changing market environment within a short period. The maturation of construction labour cost can facilitate the efficient management of contractors, influence their alternative strategies over the recruitment and retainment of skilled labour. Moreover, it is also an epitome that does concern the final success of industry upgrade & transformation, then provide a paradigm how to deal with the critical conflict between rising labour cost and restricted available manpower under different conditions.

Table 4 Panel Data Regression Analysis: Determinants of Unit Labor Cost in East Region

East Region	1995 - 2015	1995 - 2003	2004 - 2009	2010 - 2015
GDP	0.000265[a]	-0.000802	0.000597	0.000117
CLP	-0.000178[a]	-0.000295	-0.000433	0.0000194
TER	-0.000823[a]	0.000332	-0.001268[a]	-0.000159
PROF	-1.367159	-0.893373	-1.160854	-2.646009
UR	6.288969[a]	1.355822	-1.534906	10.52441[a]
Constant	49.39359[a]	61.55746[a]	87.31229[a]	20.03224
Adjusted R^2	0.939	0.978	0.979	0.972

[a] Denotes significance at 1% level.
[b] Denotes significance at 5% level.
[c] Denotes significance at 10% level.

7. Conclusion and Implication

This study investigates the critical determinants of construction labour cost fluctuations at regional level in Mainland China via panel data analysis. GDP, construction labour productivity and unemployment rate are three common factors that affect regional construction labour cost; Besides, construction profit rate is found to be another dominant determinant of construction labour cost in west region, while construction technical equipment ratio acts as a significant

 DOI 10.3311/CCC2018-049

but negative factor in central and east regions, with incremental effects towards unit labour cost from west region to central region, then east region. Regional construction development in west region shows more reliance upon cheap labour, albeit industry has a high employment generating potentials to address social unemployment, labour-intensive pattern of construction development hinders efforts towards the improvement of construction labour productivity, and the rationalization of construction labour cost. Low labour cost can create high profit gains for contractors in the short term, however, have an adverse effect on the recruitment and retention of construction workers, particularly during the period of labour shortage in construction boom. This labour strategy enables construction productivity lag far behind most sectors in rest of the economy, which is not conducive to sharp core competition in construction market in the long term. For central region, the mismatch between the levels of labour cost and construction development implies the need to raise labour wage for construction workers especially when the industry still has the capacity of satisfying the persistent growing construction demands. The establishment and development of training facilities and programs for skilled workforce becomes quite important when facing with the large-scale labour shortage. New technologies for reducing the reliance on labour inputs, substituted by construction technical plants and equipment, are recommended to introduce and promote through gradual application in construction works. Final in east region, big differences lie in less dependence on cheap unskilled labour, and more reliance on technical plants and equipment. Owing to the superior industry structure and pattern, construction labour cost in east region stays at a moderate and reasonable level, which is more resilient to external shocks. Although there are some slight fluctuations around turning points, the level of regional labour cost become mature that facilitates the efficient management of contractors, alternative strategies over retention and training of skilled construction workforce. These are critical in shaping core competition of construction enterprises, determining final success of industry upgrade & transformation, and providing a paradigm to cope with conflict between rising labour cost and limited manpower, during the crossroads of construction industry development.

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Construction Productivity and Construction Project Performance in Indian Construction Projects

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Abstract

In order to ensure the performance of a project, it should be defined in terms of some measurable key parameters. Past researchers have identified project performance parameters such as cost, safety, construction productivity, and quality. Amongst all of them, construction productivity is one of the most reliable parameters of project performance. Performance can be measured at various levels including sector, organization, activity and project level in project-based organizations. The methodology adopted to conduct the study is to collect the data through a structured questionnaire survey using convenient sampling technique. The number of variables selected from the literature for the study is 26 and the targeted data collection for the study is 125.The collected data has been analyzed using relative importance index (RII) to priorities the variables on the basis of their relative importance. The findings of the study concludes that the most significant 3 attributes impacting CPP are projected coordination meetings, coordination between all stakeholders, and top management support to PM having a relative value of 0.84, 0.82, and 0.69 respectively. SPSS 21 software tool has been used to check the reliability of the data and to perform factor analysis and the factors are pre-construction management, financial management, socio-economic management, coordination and communication management, resource management, commercial management, site management, and rework explains a variance of 14%, 10.3%, 9.1%, 7.1%, 6.3%, 6%, 5%,and 4.3% respectively.

Keywords: Construction Productivity; Construction Project Performance; Indian Construction Projects; Factors; and Project Management.

1. Introduction

The construction industry is having a significant importance in the economic, social, and infrastructure development of any country. It provides employment to the masses, promotes growth, and acts as a linkage to all the other sectors and the economy[1] [2]. Therefore the growth in the construction sector has a significant impact on the economy of the nation. Gains from higher construction productivity flow through the economy, as all industries rely on construction to some extent as part of their business investment. The construction sector is the engine of growth for any country and contributes about 8-10% to the GDP on an average[3]. Provides employment to masses and create a flow of services and goods with other sectors. The measures to be done to improve the performance of construction projects has been identified critical and troublesome problems [4]. [5].The construction industry faced a number of issues and the downward trend of productivity has been studied by a number of researchers for many years [6]. "In general terms, construction productivity can be simply illustrated by an association between an output and an input i.e. Productivity= Output/Input". Productivity is commonly defined as a ratio of a volume measure of output to a volume measure of input use (OECD Manual)[8].

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Performance can be measured at various levels including sector, organisation, activity and project level in project-based organizations. At the sector level, productivity is one of the important measures of performance of projects. Productivity has been defined as “a ratio of a volume measure of output to a volume measure of input use” (OECD, 2001, p.11). This meaning of productivity depends on available costs of output and sources of input utilized. The Construction sector experiencing a downward trend in the productivity growth and a number of a researcher working to identify and analyse the issue, and factors affecting productivity [9][10] [11][12]. The productivity of projects is measured by rewarding, controlling and monitoring the performance, and to do the benchmarking to set the firm’s future strategy that to be aligned to the basic objective of enhancing profit. Project performance metrics are used for post evaluation of the completed projects. Project performance matrix designed to measure and compare planned and actual performance of a specific project. Performance of a construction project could be influenced by a number of attributes, especially large and complex projects lay additional focus on the success/ failure attributes, because of the intensive amount of money invested, a high degree of uncertainty, the complexity of personnel required, a multiplicity of goals and problems in coordination between different stakeholders encountered. In this research paper, the author intended to define and examine the relationship between construction productivity (CP) and construction project performance (CPP). The author tests the proposition that there is a positive relationship between both of them.

Table 1 the issues and challenges in construction productivity

Impacts	*References*
Construction industry experienced a downward trend in the productivity growth	[9] [13] [10] [11]
The study pertaining to causes of time, cost overruns and low productivity in construction projects have been conducted worldwide	[14][15][16][17][18][19] [22][23]
The productivity of UK’s construction sector is declining and it is lower than as compared to few European countries	[17] [22]
Construction productivity has been affected by a number of factors, which tend to losses of revenues, delay in completion, poor quality and other issues in construction projects	[7]
The decline in productivity is one of the dangers to the economy, because it creates social conflict, and creates inflationary pressure	[19][25]
The authors concluded that the growth in construction productivity is negative	[24][6]
The author’s observed that the industry shifting is also the reason for low productivity	[6], [11], [25]
CP is one of the main drivers for completing projects within time and cost limitations	[26], [27]
Appropriate estimation of CP is quite important for preparing construction schedules and budgets	[8], [28], [29]

1.1 Objectives of the research paper are:

I. To identify the attributes affecting construction productivity through literature review.

II. Impact of the construction productivity attributes over the performance of the projects.

2. Literature review

The success of any project is repeatable and it is possible to find out a set of certain success attributes for the success of a construction project and it requires a controlled discipline hardworking [3].The productivity of construction projects is one of the measures for performance of the construction projects at the industry level based on its relationship with economic development. And most countries encounter the issue of low productivity as per the statistical data available[30]–[32]. Whereas growth in construction productivity is low and do not continue progressive for a long span of time. In construction projects, the partial measure of productivity is the measure of labour productivity, machine productivity and consumption of materials [35]. These investigations run from hypothetical work in view of understanding of scientist toward one side to organized research deal with the other end. The tools used by the past researchers are AHP (analytical hierarchy process), structures to collect data, simulation models to predict the productivity, framework to improve productivity, techniques to measure productivity, and neural networks systems.

Performance of a project can be considered as a result of the processes as well as the presence of processes [19], [33]. [3], [34]stated that construction time is important because it often serves as a benchmark for assessing the performance categories such as people, cost, time, quality, safety and health. It is studied by [35] that human factors played an important role in determining the performance of a project. Completing projects in a predictable manner of time (within schedule) is one of the important indicators of project success. Cost overrun is one of the most frequent problems with construction projects and contractors are criticized for the common occurrence of cost overrun in construction projects, [36], [37]. There are some other factors which also contribute to the cost overrun such as profit of the project, project design cost, and wastage of materials, construction productivity, cost of variation orders and cost of rework. [37]this study sets out to assess the effect of construction productivity on the project performance of Indian construction industry, using a survey design with construction professionals sampled, the study has been able to ascertain the factors affecting the construction productivity of construction projects in India, and the areas in project performance that is affected by construction productivity.

Table 2 summary of attributes/variables identified by previous researchers in the field of construction productivity

Attributes/variables	*References*
Increases in land-use regulation	[38]
Equipment, drawing, tools, availability of material, weather condition	[39], [40],[41], [42]
Labour management, rework, material, confined working space, tools	[34], [43]
Delays in inspection, decision taking, material, rework, tools and equipment	[43]–[45]
Absenteeism, Rework and lack of material	[46], [47]
Shop drawings, equipment's, motivation and support, scheduling, material	[48]
Revision in drawings, delays in inspection, competency of supervisor, martial availability	[43]
Project management, planning and scheduling, top management support, rework	[49], [50],[21]
Coordination among all team members, leadership, top management support, the flow of funds, budget update, coordination and communication, timely feedback, and owner's competence and favourable climatic condition.	[3][51], [52]
Rework, Poor supervisor competency and Incomplete drawings	[43], [53], [54]
Decision making, planning & logistics, supply chain management, labour availability, budget & cash flow management, improper construction method, frequent changes in design, supervision delay, the sequence of activities, overcrowding a job location and scope of activities.	[51], [55][26] [56][52]
Availability of material, the experience of labour, skill set and training, communication, the financial position of the client	[57][26], [40]

3. Research Methodology

3.1 Questionnaire survey

To investigate the impact of construction productivity on the performance of construction project a structured questionnaire survey method was adopted. This research paper follows a specific structured methodology. First, the literature review is conducted of all the research work related to the construction productivity and project performance, which is followed by identification of variables/attributes affecting construction productivity (table I). Thereafter a consolidated list has been prepared for the attributes identified through literature review and in addition few other variables were also included in the list identified through industry expert opinion. On the basis of these attributes, a structured questionnaire was prepared which consists of three main parts such as:

I. Introduction to the research and the basic information needed from the respondents.
II. The questionnaire itself.
III. Last part of the questionnaire is provided for suggestions from the respondents.

The respondents were asked to rank the attributes on five points Likert scale on the basis of their impact on the project performance. The points on the Likert scale (1= adversely affecting the performance, 2= significantly affecting the performance, 3= no effect on performance, 4= marginally help in improving performance and 5= significantly help in improving performance)

3.2 Sampling and data collection

The questionnaire is shared with 350 professionals working in different firms and organisations all over the Indian construction industry. The respondents were chosen randomly to make the study unbiased. A total of 125 valid responses were received with a response rate of 35.7%. The received responses were analysed using factor analysis to reduce dimensions of the attributes because it is not easy to understand the impact of 26 attributes on the project performance. The primary component analysis is used for dimension reduction.

3.3 Relative importance index (RII)

Relative importance index is used to calculate the weighted average of the different attributes selected for the study [5], [58]–[60]. RII is calculated using the formula mentioned equation (1). Where ‘r’ represent the rating provided on the Likert scale, ‘n’ is the respondents proving the same rating, and ‘N’ is the total number of valid responses received. A number of researchers applied RII to analyse the attributes and to rank them on the weighted average value calculated[3], [19], [43], [58], [61]–[64].

$$\text{Rii} = \frac{\sum_{r=1}^{5} r * n_r}{5N} \tag{1}$$

3.3.1 Most significant factors affecting CPP

The most significant factors affecting CPP are project coordination meetings, coordination between all stakeholders, and top management support to PM having a relative importance of 0.84, 0.82, and 0.69 respectively. The study reveals that coordination and interaction between the team and between the stakeholders plays a significant role in the CPP[57],[67].

Table 3 relative importance index (RII)

Total score	*RII*	*Attribute name*	*Rank*
524	0.84	Project coordination meetings	1
512	0.82	Coordination between all stakeholders	2
508	0.69	top management support to pm	3
484	0.69	Scope clarity of the project	4
477	0.69	timely payment of completed works	5
477	0.68	availability of resources	6
476	0.68	Availability of training and development for enhancing skills	7
465	0.67	regular budget update	8
461	0.67	developing and maintaining communication	9
453	0.67	PM authority to make financial decisions	10

3.4 Reliability analysis

The value of reliability is lain between 0 to 1, the more near to 1 is more the reliable results[3].Reliability analysis provides us with the confidence level that the data collected for the study is reliable and shall be used to generalise the findings of the study. The overall value of reliability for all the attributes is 0.703 which is considered as good to validate the findings[66].

Table 4 reliability analysis

Variables	Cronbach's alpha (Cα)
Overall variables selected for the study	0.703

3.5 Factor analysis

Factor analysis enables us to reduce the number of dimensions of the data and to draw a table on the basis of variance explained by the constructs/factors, and factor loading of the different attributes in factors. For the current study, the attributes having a factor loading of equal and more than of 0.4 has been considered[32]. The factor analysis reduced 26 attributes into 8 factors explaing a cumulative variance of 62.3%.

3.5.1 Pre-construction management

Pre-construction management explains the maximum variance of 14% for the attributes impacting CPP. The attributes having the factor loading more than 0.4 are inadequate project formulation, in the beginning, contractual disputes, design capability, obsolete construction equipment, and technology, and human resource and labour strike having a factor loading of 0.65, 0.85, 0.8, 0.85, and 0.67 respectively.

3.5.2 Decision management

Decision management explains a variance of 10.3% for the attributes impacting CPP. The attributes having the factor

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loading more than 0.4 are PM authority to make financial decisions, willingness to adopt change, availability to adopt changes, use of inappropriate planning tools, and claim issues having a factor loading of 0.48, 0.57, 0.57, 0.54, and 0.46 respectively.

3.5.3 Stakeholder's management

Stakeholder's management explains a variance of 9.1% for the attributes impacting CPP. The attributes having the factor loading more than 0.4 are quality, supply chain, political and economic environment, and social environment having a factor loading of 0.55, 0.79, 0.61, and 0.55 respectively.

3.5.4 Coordination and communication

Coordination and communication explain a variance of 7.1% for the attributes impacting CPP. The attributes having the factor loading more than 0.4 are scope clarity of the project, coordination between all stakeholders developing and developing and maintaining communication, and project coordination meetings having a factor loading of 0.49, 0.63, 0.49, and 0.4 respectively.

3.5.5 Resource management

Resource management explains a variance of 6.3% for the attributes impacting CPP. The attributes having the factor loading more than 0.4 are timely payment of completed works, and availability of resources having a factor loading of -0.61, and 0.4 respectively. Timely payment having a negative factor loading because it's negatively impacting the performance of construction projects.

3.5.6 Commercial management

Commercial management explains a variance of 6.3% for the attributes impacting CPP. The attributes having the factor loading more than 0.4 are a regular budget update, conflict of interests among team members, and top management support to PM having a factor loading of 0.6, -0.4, and 0.57 respectively. The conflict of interests is negatively impacting the performance of the project.

3.5.7 Site management

Site management explains a variance of 5% and it acts as a factor instead of an attribute and having the factor loading of 0.62.

3.5.8 Rework

Rework explains a variance of 4.3% and it also acts as a factor instead of an attribute and having a negative factor loading of -0.57.

Table 5 factor analysis

Attribute/variable name	Factor loading	%age of variance explained
Pre-construction management		*14%*
Inadequate formulation of the project in the start	0.65	
Contractual disputes	0.85	
Design capability and frequent design changes	0.80	
Obsolete construction equipment, and technology	0.85	
labour and human resource management	0.67	
Financial management		*10.3%*
PM authority to make financial decisions	0.48	
Willingness to adopt change	0.57	
Availability of training and development to enhance skills	0.57	
Use of inappropriate planning tools and techniques	0.54	
Claim geniuses	0.46	
Socio-economic management		*9.1%*
Quality	0.55	
Supply chain	0.79	
political and economic environment	0.61	
social environment	0.55	
Coordination and communication		*7.1%*

Scope clarity of the project	0.49	
Coordination between all stakeholders	0.63	
developing and maintaining communication	0.49	
Project coordination meetings	0.40	
Management of resources		*6.3%*
Timely payment of completed works	-0.61	
Availability of resources	0.40	
Commercial management		*6%*
Regular budget update	0.60	
Conflict of interests among team members	-0.40	
Top management support to PM	0.57	
Site management		*5.0%*
Site clearance/availability	0.62	
Rework		*4.3%*
Rework	-0.57	
Total variance explained		*62.3%*

4. Conclusion and Recommendation

This study analyses the impact of CP attributes over CPP using a structured questionnaire survey. The minimum RII value of top 10 attributes selected for the study is 0.67 which concluded that the attributes selected for the study having a significant impact on CPP. The cumulative variance explained by 8 factors is 62.3% i.e. by controlling and monitoring these 8 factors chances of success is 62.3%. The maximum variance is explained by pre-construction management, and the least variance is explained by rework (act as a construct) are 14.3%, and 4.3% respectively. Three attributes reflect negative factors loading are timely payment, conflict of interest, and rework. This study helps in defining the relationship between CP and CPP.

5. Limitation

This paper attempts to identify the relationship between CP and CPP and recommends the framework for the industry to grow sustainably and deliver projects successfully. This study may be conducted using a structured questionnaire survey in India and to validate the results of the study similar kind of study is required to be conducted in the other regions of the country to have more reliable findings[67].

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Construction Scenario for Water Supply Infrastructure in North Korea

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Abstract

The plan on residential supply in North Korea is needed for stabilization of Korean Peninsula after unification. While infrastructure and building construction are essential parts of this preparation, water-supply infrastructure is to be considered as a first step for establishing a stable residential environment. An arranged database on water resources in North Korea is primarily needed in order to plan for a mass supply on water-supply infrastructure and residential construction. Therefore, this study proposes a database of water resource in North Korea and a construction scenario on water-supply infrastructure. The results of this study are expected to be used as probable data for the construction of water-supply infrastructure in North Korea.

Keywords:Water resource; Construction scenario; North Korea; Korean peninsula; Infrastructure

1. Introduction

The Korean government is in need of preparing for unification scenarios on the stabilization of the Korean Peninsula. In preparation of these scenarios, the government is collecting and analyzing information on the current environment and infrastructure of North Korea. Due to the diplomatic policy of North Korea towards other countries that resulted in a long-term disconnection with the outside, current method of collecting information on the environment and infrastructure of North Korea is indirect through literature and satellite photographs. Since information on environment and infrastructure of North Korea is currently collected indirectly using satellite photographs, most of the information inevitably has low accuracy compared to that of direct method processed via survey or observation. Nevertheless, current diplomatic policy of North Korea restricts access to information on North Korea that is necessary for supplying infrastructure in North Korea.

Meanwhile, massive defection of North Korean is expected to be caused by the famine after unification of Korean peninsula [1]. Under the current situation with the lack of information on current environment and infrastructure of North Korea, there is a difficulty on preventing the famine by constructing infrastructure in the North. From the point of view of constructing infrastructure in North Korea, systematically collecting information on environment and infrastructure in a certain target area is a first step towards providing decision-making standards on appropriate size and location of infrastructure under consideration of resource supply. A comprehensive and systematically organized information on environment and infrastructure also serves as an important factor for improving a efficiency on the rehabilitation plan for existing infrastructure in North Korea.

Although this indirect method of collecting information on the environment and infrastructure of North Korea has strengths in terms of applicability in more diverse fields compared to a direct method, there is certain information that cannot be collected caused by an exclusive diplomatic policy of North Korea. For example, the lack of information on

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hydraulics and water resources in North Korea makes it difficult to prepare scenarios for constructing water-supply infrastructure in North Korea right after the unification of the Korean peninsula. In order to solve this difficulty, it is necessary to systematically collect the information on water resources in North Korea, which serves as a raw database on preparing scenarios for constructing water-supply infrastructure in North Korea.

Therefore, this study is conducted to collect raw data by using indirect method and analyze the data and extract necessary information for collect information on water resources in Hwanghaenam-do – a province in North Korea - for constructing water-supply infrastructures in the region after the unification of the Korean Peninsula. Also, this study proposes a scenario of water-supply infrastructure construction for assisting the decision-making process on the size and location of water-supply infrastructure in Hwanghaenam-do region after the unification of Korean peninsula.

The indirect method for collecting information on water resource in Hwanghaenam-do is conducted by comparing satellite photographs of Hwanghaenam-do and reports on water resources in the region. To prepare the scenario for water-supply infrastructure construction in Hwanghaenam-do, the collected information on environment and infrastructure of the region is used as the database for the decision-making process on the size and location of water-supply infrastructure construction in the region.

2. Literature Review

With a vast plain and abundant water resource in the region, Hwanghaenam-do has been served for specific purposes such as cultivating food and covering food consumption of North Korea [2]. After unification of Korean peninsula, the government of South Korea has to invest in infrastructure that can satisfy food consumption of North Korean for preventing massive defection. Thus, constructing water supply infrastructure in Hwanghaenam-do and utilizing the region as food supply area can prevent massive defection of North Korea. In this reason, prior to developing a plan on constructing water supply infrastructure in Hwanghaenam-do, collecting information on water resources in the region is preferentially needed.

There are less than ten reports that collected and analyzed information on water resource in North Korea, and the information under scope of these researches is less than 5% of the total observable water resource. There has been a study that included databases on approximate location of water resource in Hwanghaenamdo [3], but there has been no research that contained information on watermark area and volume of water resource in the region that is necessary for the decision making of size and location on the infrastructure. Thus, an absence of these information makes it difficult to decide the precise size and location of water-supply infrastructure in the region after unification of Korean peninsula.

Most of the previous studies focused on the rates of water usage in North Korea by roughly comparing total volume of water resources in North Korea and the demand for people living in the country [3]. Those studies insinuated a total amount of water resource in North Korea after unification, but the results did not consider the famine caused by shortage on capacity of water-supply for people living in the North. This famine could be cause of the massive defection of North Korean after unification of Korean peninsula.

Since the Ministry of state construction is not deeply concerned with managing water supply in the country, residents in the North solve the water-demand through reservoirs by themselves. This phenomenon is caused by the interior condition of North Korean water-supply. In the literature, however, information on water resources in North Korea is only focused on river and lake, and neglects the importance of reservoir. The number of river and lake in North Korea is less than 1% of the total water resources in North Korea [4]. Therefore, if the government wants supplying water to North Korean after unification of Korean peninsula, the government will have to collect information on reservoirs in North Korea.

In order to supply water resources immediately after the unification of the Korean peninsula, water-supply infrastructure should be constructed using reservoirs which account for the largest amount of water resources existing in North Korea. Due to the immediacy of stabilizing the regions in North Korea, applying the method using the existing water resources in the North for constructing water-supply is preferred to methods of applying modern technologies of the South that takes a long time for application. Thus, this study provides the database of information on size of reservoirs in Hwanghaenam-do and calculates approximate volume of the reservoirs using watermark area - volume correlation graph. Also, this study proposes a construction scenario of water-supply infrastructure in North Korea after unification of Korean peninsula.

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3. Methodology

In order to collect the information on water resources in Hwanghaenam-do, it is necessary to collect precise information on location of water resources based on comparing satellite photographs of Hwanghaenam-do and literature. To compare the information on location of the water resources, collecting and analyzing the previously proposed information in literature is primarily need. The scope of research in previous literature is restricted to village. Thus, satellite photographs of Hwanghaenam-do region of North Korea were used to verify the location of reservoirs.

3.1. Location of water resources

The information on approximate location of the water resources in Hwanghaenam-do is collected and analyzed to classify into city or county, as follows (Table 1):

Table 1. Information on location of water resources.

Province	City	Number of reservoir
	Haeju	4
	county	Number of reservoir
	Kangryong-gun	27
	Kwail-gun	4
	Paechon-gun	9
	Pyoksong-gun	22
	Pongchon-gun	9
	Samchon-gun	33
	Songhwa-gun	5
	Sinwon-gun	11
Hwanghaenam-do	Sinchon-gun	14
	Anak-gun	13
	Yonan-gun	9
	Ongjin-gun	31
	Ryongyon-gun	8
	Unryul-gun	5
	Unchon-gun	16
	Changyon-gun	10
	Chaeryong-gun	2
	Chongdan-gun	6
	Taetan-gun	6

The number of water resources in Hwanghaenam-do is 244, and 238 of 244 water resources exist as reservoirs. The information on location of water resources in literature is accuracy, so correcting the information is conducted before calculating the reservoir.

3.2. Watermark area and Volume of water resources

In order to collect the total volume of water resources in Hwanghaenam-do, information on the watermark area and volume of each water resource is needed. First, the watermark area of water resources (Figure 1b) is calculated by extracting area (Figure 1c) from polygon covering the water resource of satellite picture (Figure 1a). These polygons consist of multiple points located on the border of water resources.

 DOI 10.3311/CCC2018-051

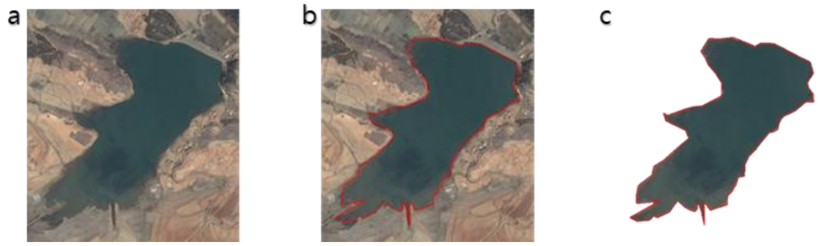

Fig. 1. (a) satellite picture of reservoir located in Hwanghaenam-do; (b) watermark area of the reservoir; (c) extracted area of the reservoir.

The volume of water resource is linearly proportional to the watermark area [5], thus allowing the calculation of the volume of water resource. In this study, we calculate the volume of water resources based on watermark – volume correlation graph (Figure 2a) and empirical correlation graph (Figure 2b) of Iksan.

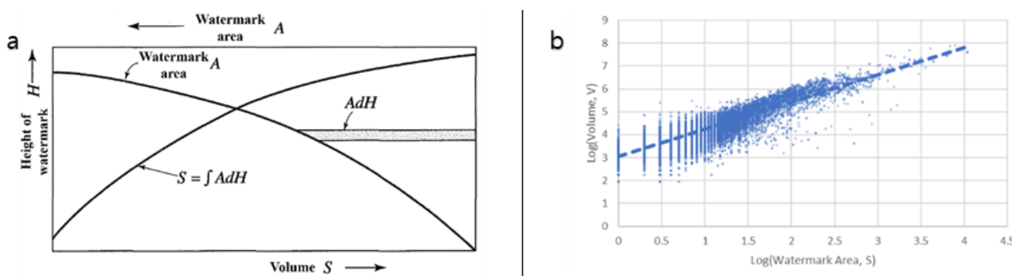

Fig. 2. (a) watermark area – volume correlation graph [6]; (b) correlation graph of reservoirs located in South Korea.

3.3. Construction scenario on water-supply infrastructure

Table 1 that has been previously proposed shows that the water resources in the 20 counties and cities of Hwanghaenam-do are evenly located. However, due to the difference in volume of water resources, it is necessary to secure the efficiency of water supply through an optimal construction scenario of water supply infrastructure in Hwanghaenam-do. Thus, the scenario includes information on size and location of water supply infrastructure to be constructed.

In this study, decision-making on size and location of infrastructure to be supplied in future is conducted by finding overlapped area of concentric circles figuring the characteristics of water resources. Concentric circles are regulated by the average size of the water supply infrastructures in Iksan city adjacent to the Kum River basin located in Honam Plain, the largest granary zone in South Korea. These maps below show concentric circles of the water resource and infrastructure as figure 3a and figure 3b respectively.

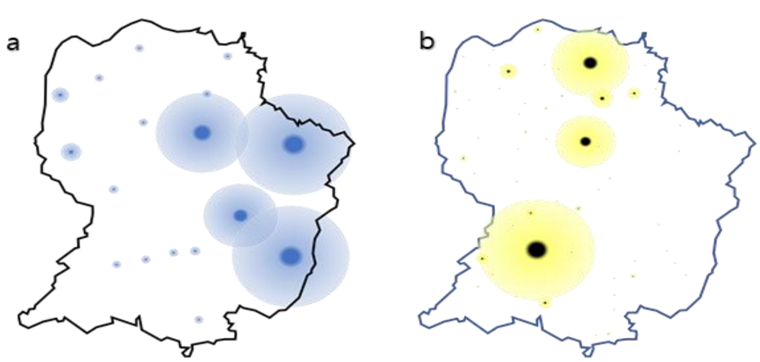

Fig. 3. (a) volume of water resource located in Iksan; (b) water-supply infrastructure located in Iksan.

The map of Iksan (Figure 3) shows that water resources and water supply infrastructures is uniformly located. The construction scenario of water supply infrastructures on Iksan city is the result of long-term preparation under thorough investigation of water resources. Due to inaccessibility to construction sites and shortage of time in case of unification of the Korean Peninsula, this study has problems conducting a simulation concerning all size and location of resource and infrastructure. Thus, this simulated scenario by limiting the scope of the size and number of infrastructure.

4. Results and Discussion

4.1. Information on water resources

The information on the location and watermark area, and volume of water resources in Anak-gun, a district in Hwanghaenam-do, is collected through the comparison of previous researches (Figure 4a) and satellite image (Figure 4b).

a

Name of water resource	Location	Watermark Area (m^2)	Volume ($10^6 m^3$)
Hwasukdong	①	14,131	0.0326
Hwapyung	②	76,529	0.3598
Gumgang	③	208,131	1.1647
Pyungjung	④	42,102	0.0971
Yeundeung	⑤	530,000	2.3491
Oryong	⑥	13,837	0.0319
Tongsan	⑦	64,432	0.3029
Panryuk	⑧	22,314	0.0515
Hanjunggol	⑨	21,828	0.0504
Dolchan	⑩	37,542	0.0866
Guwal	⑪	3,382,236	18.6887
Osan	⑫	232,251	1.2996
Myogakgol	⑬	57,491	0.2703

b

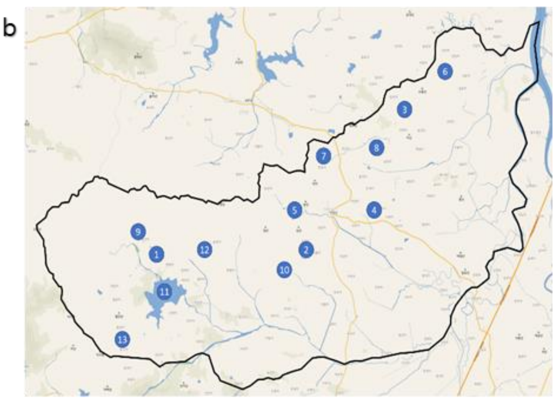

Fig. 4. (a) information on water resources located in Anak-gun; (b) map of spots marking the location of water resource.

4.2. Construction scenario of water-supply infrastructure

The information on the location and size of concentric circles (Figure 5a) and the infrastructures that can be constructed immediately after the unification, located in the map (Figure 5b) based on the analyzed database on water resources.

a

Location	Drainage area (km^2)	Pump capacity ($10^3 m^3/sec$)
1	9.5016	0.6512
2	7.0028	4.3711
3	9.4531	0.3559
4	10.5065	0.9685
5	21.4851	0.9438
6	28.9312	0.6193
7	21.3274	0.5149
8	19.7194	4.7403
9	23.5375	2.1662
10	18.3064	27.7392
11	7.5691	7.8643
12	21.7754	0.2627
13	19.5402	26.8080
14	2.2270	1.6100
15	33.3187	0.2406
16	27.3130	27.8713
17	18.1045	60.0491
18	19.6942	0.4977
19	14.3101	1.8369
20	23.4408	84.7846

b

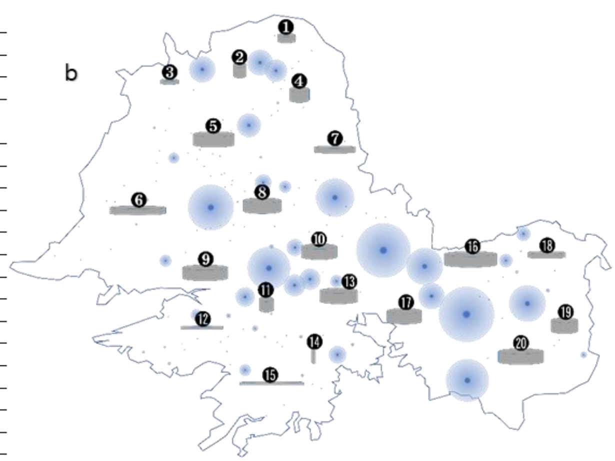

Fig. 5. (a) result of simulation of construction scenario; (b) map of Hwanghaenam-do showing the information on infrastructure.

4.3. Discussion

The water resources concerned in this study account for only seven percent of the total water resource in Hwanghaenamdo, in response to the number of facilities but they have 60 percent volume. There 23.1 million residents in Hwanghaenam-do, and 58.1 percent of them are engaged in agriculture [2]. The required volume of water resources for residents engaged in agriculture and other residents are respectively about 270 cubic meter per second(CMS) and 11 CMS, insinuating that about 281 CMS is needed for every resident of Hwanghaenam-do. The total volume of water resources calculated in this study is 1.27 billion tons, and about 255 CMS can be supplied for water-supply through the construction scenario.

The volume of water resources concerned in this study contains only 60 percent of the total volume, showing that the total volume of water resources in Hwanghaenam-do can satisfy the water usage for residents. However, Figure 5b shows the possibility of suffering from famine in the western part of Ryongyon-gun after unification because of shortage on capacity of the water-supply infrastructure. The shortage on capacity of the infrastructure in the region is caused by shortage of water resource, so this shortage can be solved by supplying the water from another region through improved infrastructure in a long-term. The results of this study show that a stable supply of water is possible for the residents in Hwanghaenam-do after unification.

5. Conclusion

This study proposed the construction scenario of water-supply infrastructure as an alternative to the pandemonium that may arise after unification of Korean peninsula. The proposed scenario could be made by collecting the information on water resources in North Korea that did not exist in literature with the level of details proposed in this study. Previous studies have reported that about 1 million North Koreans would escape from their country due to famine after unification [1]. However, Hwanghaenam-do is the largest granary zone in North Korea and is regarded as an area in which such massive defection of North Korean does not occur. The results of this study show that the food resources produced in the Hwanghaenam-do under stable water-supply can minimize the famine that may arise after unification.

Previous studies on water resources in North Korea have low applicability due to limitations of research scope, and thus cannot be used as data to be pre-emptive measure against the famine after unification. This study proposes these results to be used as factors for constructing infrastructures that can provide drinking water and irrigation water for residents of Hwanghaenam-do after unification based on the information on water resources in Hwanghaenam-do. The scenario suggested from this study expects that North Korea can be able to secure water and food resources through the water-supply infrastructure and provide a stable environment.

This study does not comprehend all regions in North Korea for proposing construction scenarios. Exclusion of other regions is due to lack of information on the spread of population in North Korea. The lack of information makes it hard to decide the characteristics of the infrastructure and to propose a sufficient number of infrastructure to be supplied when simulating the construction scenario. To overcome this difficulty, future research is needed to subdivide the scenario as short-term, medium-term, and long-term. The subdivided scenario is expected to be able to supply water resource more stably for residents living in North Korea.

Acknowledgements

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Correlation between Contract Type Selection and Cost Growth in U.S Army Corps Construction Projects

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Abstract

In United States federal construction projects, government contract managers seek to negotiate a contract type that will result in a reasonable level of contractor risk, as well as provide the contractor the greatest incentive for improved performance. The Federal Acquisition Regulation provides government contract managers a variety of contract types to choose from to provide flexibility in acquiring a wide range of required supplies and services. Contract types can be broadly group into two categories: fixed price and cost-reimbursement contracts. The aim of this research was to investigate the impact of contract type selection on cost growth in USACE construction projects. Based on the quantitative and qualitative analysis conducted, contract type selection does have an impact on construction cost growth. In addition, it can be concluded that negotiated non-competitive task orders and more specifically, those, which use RSMeans and a contractor coefficient, are best at reducing construction cost growth in federal construction projects.

Keywords: Cost Growth, Time Growth, Contract Type, Federal Acquisitoin Regulation

1. Introduction

Contract type selection is a key component in any successful construction project as contract risk is distributed between the contracting parties via the selection of contact type. In federal construction projects, government contract managers seek to negotiate a contract type that will result in a reasonable level of contractor risk, as well as provide the contractor the greatest incentive for improved performance.

A significant amount of research has been conducted on the impact delivery methods (i.e. design build, design bid build, CM at Risk, etc.) and acquisition methods (i.e. negotiated procurement, low bid, or sole source) have on cost growth for both public and private construction projects. However, there is limited research on how contract type affects contract cost growth, specifically in public projects. This research seeks to determine the correlation between contract type selection and construction cost growth in U.S. Army Corps of Engineer (USACE) projects.

1.1. Research Background

The Federal Acquisition Regulation (FAR) with its department and agency supplements is the primary regulatory guidance for all USACE acquisitions. In fiscal year 2016, USACE awarded over $10 billion in construction contracts. Much of that being awarded on firm-fixed priced contracts based on the FAR's preference for firm-fixed price contracts for construction services.

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For many years, the standard USACE practice was to award construction projects via sealed bid. This meant awarding firm-fixed price contracts to the lowest bidder with design-bid-build (DBB) as the prescribed delivery method. Although private sector construction projects had seen the benefits of utilizing design build (DB) delivery in certain projects, it was not until 1996 when the FAR was updated to allow for the use of DB in federal construction projects [1]. As building technologies continue to advance, construction projects become more complex with an increasing number of unknown challenges. These unknown factors make project cost estimating more difficult, resulting in project cost growth. Research has confirmed that the likelihood of cost overruns increase with contract size and complexity [2].With so many unknowns associated with complex construction projects, USACE has moved from traditional low bidder awards to negotiated best value procurements. Based on research conducted on both private and public projects, negotiated best value procurements typically result in less cost growth when compared with lowest bid awards [3]. Even though several studies confirm these findings, none of these studies considered how contract type might affect costs. The aim of this research is to investigate the impact of contract type selection on cost growth in USACE construction projects. The researchers seek to expand the body of knowledge regarding contract type selection in USACE construction projects. This research is particularly relevant as Government projects continuously face shrinking budgets and limited numbers of qualified personnel capable of overseeing construction projects. The research scope is limited to USACE construction projects including interviews conducted with various USACE project and contract managers. Quantitative data is gathered from various construction projects from four different district offices in the southeast United States. Qualitative data comes from interviews with six district contracting chiefs, project managers, and legal counsel from each of the four district offices from which the quantitative data was collected.

2. Literature Review

The FAR provides government contract managers a variety of contract types to choose from to provide flexibility in acquiring a wide range of required supplies and services. Contract types can be broadly group into two categories: fixed price and cost-reimbursement contracts. The two main differences distinguishing these groups is degree and timing of risk assumed by the contractor for the costs of performance and the amount and nature of the profit incentive offered to the contractor for achieving or exceeding specified goals. Contract types can be arranged on a continuum with firm-fixed-price contracts on one end, in which the contractor bears all the risk for cost growth and the resulting profit or loss. On the other end a contract type of cost-plus-fixed-fee, in which the government bears all the risk for cost growth and the negotiated contractor fee is fixed. Selecting the appropriate contract type should result in a reasonable level of contractor risk, as well as provide the contractor the greatest incentive for improved performance.

When project requirements are well defined and the level of complexity reasonably low, using a firm fixed price contract is the best contract type to motivate contractor based on basic profits motives. As project size and level of complexity increases, other contract types should be considered and negotiations should be directed toward selecting a contract type that will appropriately tie profit to contractor performance. The FAR recommends that government contract managers consider several factors when selecting contract types to include: level of competition in the market, cost/price analysis, complexity of project, urgency of requirement, project duration, and acquisition history. It is relevant to understand the nuances of various contract types to explore cost growth trends between them.

2.1. Fixed Price Contract

Fixed price contracts establish a firm price for the completion of a project. Within the fixed price *category*, there *is a range* of contract types. Firm-fixed-price contracts are the most commonly used fixed price contract type. These contracts establish a price that is not subject to any adjustment based on the contractor's actual cost incurred during contract performance. This places maximum risk for all costs and resulting profit or loss on the contractor. This contractual relationship provides contractors with the maximum incentive to control costs. If performance uncertainties are low and costs can be reasonable estimated, contractors are willing to enter into firm-fixed price contracts; however, as uncertainties increase, use of firm-fixed price forces contractors to factor in the additional risk of these unknown unknowns in their prices. Thus, potentially leading to higher pricing.

2.2. Cost Reimbursement Contracts

When using cost-reimbursement contracts the FAR allows for the payment of all allowable and allocable costs incurred to the extent prescribed in the contract. These contracts establish a ceiling that cannot be exceeded without agreement and approval of the government-contracting officer. Cost-reimbursement contracts place maximum risk on the government if the project cannot be completed within expected costs. With the high level of uncertainties involved in large and complex projects, contractor's may be unwilling to accept the risk of working under fixed-price contracts, which makes cost-reimbursement contracts necessary to transfer risk from the contractor to the government. When a decision to use a cost-reimbursement contract is selected, the Government not only accepts additional performance risk, but also accepts the burden of additional oversight and management requirements.

2.3. Incentive Contracts

In recent years, there has been a move toward the use of incentive contracts in public and private projects. The FAR states that incentive contracts are appropriate when services can be acquired at lower costs or with improved performance, by relating the amount of profit or fee payable under the contract to the contractor's performance. Per FAR 16.401, incentive contracts satisfy project objectives by establishing reasonable and attainable targets that are clearly communicated to the contractor and includes appropriate incentives designed to motive contractors to achieved these desired targets (i.e. discourage contractor inefficiency and waste). Incentive contracts work by establishing a predetermined formula, based on specified performance or delivery targets, in which profits or fees increase based on achieving targets or decrease when targets are not met.

2.4. Indefinite Delivery/Indefinite Quantity Contracts

USACE has seen a significant increase in the utilization of Indefinite Delivery/Indefinite Quantity (IDIQ) contracts for construction services because of the reduced procurement time and administrative burden they can provide (Stanford M. Scott et al., 2016). IDIQs are contractual relationships that allow the Government to place individual task-orders with contractors as projects become known, within stated limits, for a fixed period. While the IDIQ itself does not contain specific project performance specifications, the individual task orders do. When utilizing IDIQ contracts, the Government can award single award task order contracts (SATOC) or multiple award task order contracts (MATOC) in which each contractor within a pre-established pool must be given fair opportunity to compete for each task order. When issuing task orders against a non-competitive SATOC, some USACE offices utilize agreed upon unit prices guides like RSMeans and a contractor coefficient to determine the contract price.

Although there are many advantages of utilizing IDIQ contracts, critics point out that these contracts can limit competition to either a single contractor or small pool of contractors which could inadvertently lead to higher costs by limiting competition. Additionally, broad scopes of these IDIQs can limit small business participation [3]. The small business community has been critical of the increased use of IDIQ contracts due to being adversely impacted by contract bundling [4]. Thus, small business lobbying has resulted in changes to the Small Business Act, which make contract consolidation and bundling a much more difficult obstacle for Government contract managers to overcome.

2.5. Cost Growth

2.5.1. Identified Causes

A significant amount of research has been conducted studying the impact delivery methods (i.e. design build, design bid build, CM at Risk, etc.) and acquisition methods (i.e. negotiated procurement, low bid, or sole source) have on cost growth for both public and private construction projects [1, 2]. Cost growth has been attributed to unanticipated project schedule growth, the inability to accurately anticipate material or labor shortages, rework, unexpected site conditions, and owner requested changes. Multiple studies have suggested that the probability of cost overruns increases with the size, complexity, and number of change orders issued during project performance [5]. Unclear objectives, scope creep with no change control system, inappropriate procurement approach, poor leadership with unqualified staff, poor planning with unrealistic time scales, and overall poor contract management are seen as some of the factors leading to cost growth and potentially project failure [5].

2.5.2. Federal Requirements

Some researcher have found that public owners are exposed to additional risk due to additional requirements based on laws and regulations placed on federal construction projects[6]. The FAR, Buy American Act, Davis Bacon Act wage rates, and socio economic considerations all increase the cost of public sector construction projects [7]. Public projects seek to deliver best value to owners, but unlike private sector projects, public projects must do so while maintaining the public's trust and fulfilling public policy objectives. In addition to providing assurances for fair and competitive source selections, the FAR requires that all public projects comply with all administrative, financial, labor, and environmental laws, which by their very nature result in increased project costs [8].

2.5.3. Small Business Considerations

With the passing of the Small Business Act in 1953, US Congress has decided that government should aid, counsel, assist, and protect, insofar as is possible, the interests of small business concerns in order to preserve free competitive enterprise. This will ensure that a fair proportion of the total purchases and contracts or subcontracts for property and services for the government will be placed with small business enterprises [4]. This congressional intent is further promulgated through FAR regulations stating that all federal acquisitions below $150,000 be set aside exclusively for small business competition. Additionally, for acquisitions above $150,000 in which market research determines that two or more small business will likely compete, these acquisitions must be set aside exclusively for small business competition. For construction projects over $1.5 million that are not awarded to a small business, contractors must have small business subcontracting plans to the extent there are subcontracting opportunities. These plans establish subcontracting goals for various small businesses socio-economic categories i.e. women owned, HUB Zone and service-disabled veteran owned [9]. These socio-economic requirements tend to lead to increased project costs due the difficulty in finding and securing sub-contractors under each of the required socio-economic categories.

To help expand the industrial base and support small disadvantaged businesses, the U.S. Small Business Administration (SBA) created the "8(a) Business Development Program". This program allows Federal agencies to award sole-source contracts up to $4 million to 8(a) firms. USACE has used this program extensively to award $4 million SATOCs to 8(a) firms, which allows USACE to quickly issue task orders for smaller individual projects.

This literature review illustrates that there are several factors that lead to construction cost growth, many of which may be out of the control of the contracting parties. However, previous studies have shown that the chosen delivery method or acquisition strategy play a significant role in predicting the likelihood of construction cost growth. Further research is needed to determine how 'contract type selection' impacts cost growth, while taking into consideration the impacts of delivery method, acquisition strategy, and small business requirements.

3. Research Methodology

A mixed method study involving qualitative data and quantitative data were used in the conduct of this research.

3.1. Quantitative Data

The quantitative data used for this research comes from completed construction projects awarded out of four USACE district contracting offices in the southeast United States. With the research aim to investigate the effect contract type selection has on cost growth in USACE construction projects, the chosen data set covers various delivery methods, acquisition methods, and most importantly a variety of contract types. All quantitative data was obtained via the USACE Electronic Data Warehouse (EDW) and validated by comparison to the Federal Procurement Data System - Next Generation (FPDS-NG) system. These two separate databases collect various data concerning USACE construction projects. Checking data in both sources ensured the accuracy of data considered for this research. Instead of using actual project names and contract numbers a generic project number usage to ensure anonymity. Cost growth is calculated as a percentage of final project cost versus awarded project contract cost. Time growth is also calculated as a percentage of extra days used to complete the project versus original days

3.2. Qualitative Data

The qualitative data used for this research comes for interviews of six government employees that are currently involved in awarding and administering construction projects on behalf of USACE. These individuals include professionals with titles contracting chiefs, project managers, and legal counsel from each of the four district offices from which the quantitative data was selected. USACE contracting chiefs are the highest ranking contracting official within their respective districts and are accountable and responsible for all contracts awarded within their offices. Each of these contracting chiefs hold unlimited contracting officer's warrants, which allow them to enter into contracts on behalf of the Government for any dollar amount. USACE project managers hold ultimate responsibility for the successful completion of a project under their watch.

Each interview be with questions related to their role within the organization and what types of construction projects they support. Then each interviewee is asked a series of questions related to acquisition method and contract type selection, and how these selections impact cost growth of a project. The overall intent of the interviews is to determine the types of contracts used by the interviewees, as well as determine their feelings on how contract type selection impacts project cost growth.

4. Results

The results for the research are organized by the type of data collected.

4.1. Quantitative Data

The quantitative data collected for this research came from 171 completed construction projects awarded out of four USACE district contracting offices in the southeast United States. The projects in the sample ranged in size from $4,237 to $16,231,843, with average size of $946,372. The projects within the sample include work for mostly sustainment, restoration, and modernization (SRM) type work and small new construction of maintenance and storage facilities on military installations. These projects include construction of new facilities, mechanical-electrical-plumbing (MEP) repair/replacement projects, road and airfield pavement repairs, roof replacements, water/sewer system upgrades, and miscellaneous maintenance and restoration work on existing facilities. All projects within the sample were awarded and completed between October 2014 and September 2017. Contract type, cost growth, and time growth were determined for each construction project. Once collected, the data was sorted by contract type and analyzed for cost and time growth. Results of the analysis is presented in a tabular format, along with associated discussion.

Table 1: Summary of Contract Changes for Competitive Task Orders

Project Type	Number of Projects	Average Cost Growth	Average Time Growth	Projects with Cost Growth	Projects with Time Growth
MEP Repair/Replacement	13	4.43%	25.11%	11	10
Misc. Maintenance/Restoration	45	8.38%	29.53%	20	27
New Facilities	5	2.62%	18.08%	2	2
Paving	4	11.34%	51.88%	1	3
Roof Replacement	3	-25.33%	22.57%	0	2
Water/Sewer Upgrade	1	7.79%	64.00%	1	1
Summary	71	5.99%	29.36%	35	45

Table 1 presents the changes to contracts that were acquired using a competitive task order. Competitive task order project sample had an average of 6% cost growth and nearly 30% time growth. However, nearly 50% of projects had cost growth and 63% of projects had time growth.

Table 2: Summary of Contract Changes for Firm Fixed Price Projects

Project Type	Number of Projects	Average Cost Growth	Average Time Growth	Projects with Cost Growth	Projects with Time Growth
MEP Repair/Replacement	2	9.40%	14.40%	1	2
Misc. Maintenance/Restoration	6	3.06%	19.57%	4	6
New Facilities	7	5.87%	14.26%	2	4
Paving	3	20.70%	7.13%	2	1
Water/Sewer Upgrade	1	21.05%	59.10%	1	1
Summary	19	8.50%	17.18%	10	14

Firm fixed price (FFP) acquisition method type contract changes are presented in Table 2. FFP acquired projects had an 8.5% cost growth and 17.18% time growth. More than 50% of the projects had cost growth and 73% of them had time growth.

Table 3: Summary of Contract Changes for Non-Competitive Task Orders

Project Type	Number of Projects	Average Cost Growth	Average Time Growth	Projects with Cost Growth	Projects with Time Growth
MEP Repair/Replacement	2	0.00%	4.60%	0	1
Misc. Maintenance/Restoration	72	1.35%	13.10%	11	18
Paving	5	3.41%	17.04%	1	2
Roof Replacement	2	3.72%	16.40%	1	2
Summary	81	1.50%	13.21%	13	23

Table 3 shows contract change data for projects acquired using non-competitive task order acquisition method. The data shows an average cost growth of 1.5% and time growth of 13.21%. Only 16% of projects has cost growth and 28% of the projects had time growth.

Table 4: Comparison of cost growth by contract type

	Competitive Task Order	Firm Fixed Price Projects	Non-Completive Task Oder	Total Projects
Mean	5.99%	8.50%	1.50%	4.14%
Standard Deviation	23.88%	15.63%	5.40%	16.76%

Table 4 illustrates the average cost growth and standard deviation for each of the contract types used in the sample. The average percentage cost growth for projects within the sample was 4.14%. When comparing the different contract types, non-competitive task orders outperform competitive task orders and firm-fixed price standalone contracts when it comes to percentage of average cost growth. The average percentage cost growth for non-competitive task orders was a very low 1.50%, with competitive task orders and firm-fixed price standalone coming in at 5.99% and 8.50% respectively. Although competitive task orders have lower average cost growth than firm-fixed price standalone, the firm-fixed price standalone had a lower standard deviation meaning there is less variability in cost for firm-fixed price standalone when compared the competitive task orders. Not only did the non-competitive task orders outperform the other contract types, but with a standard deviation of 5.40%, there is significantly less variability in cost growth for non-competitive task orders when compared to the other contract types. This low average cost growth and standard deviation, could be because many of these non-competitive task orders were awarded based on agreed upon unit prices guides like RSMeans and a contractor coefficient to determine the contract price. This requires that the contractor has a very clear understanding of the project requirements as the only item truly being negotiated is level of effort for labor rates.

Table 5: Comparison of time growth by contract type

	Competitive Task Order	Firm Fixed Price Projects	Non-Completive Task Oder	Total Projects
Mean	29.36%	17.18%	13.21%	20.36%
Standard Deviation	34.52%	17.75%	27.36%	30.59%

Table 5 illustrates average time growth percentages and standard deviation for each of the contract types used in the sample. The average time growth for all the projects within the sample was 20.36% with a standard deviation of 30.59%. This high standard deviation is indicative of the high degree of variability of time growth within the sample. When comparing the different contract types, again the non-competitive task orders outperform the other contract types with average time growth at 13.21%. Unlike average cost growth, firm-fixed price standalone contracts outperform competitive task orders in terms of average time growth. With an average percentage time growth of 17.18%, firm-fixed price standalone contracts experience less average time growth than competitive task orders and based on standard deviation, have less variability than both competitive and non-competitive task orders.

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4.2. Qualitative Data

The qualitative date collected for this research came from interviews of six government employees that are currently involved in awarding and administering construction projects on behalf of USACE. These individuals include contracting chiefs, project managers and legal counsel from each of the four district offices from which the quantitative data was selected. The data was analyzed using thematic analysis techniques and presented under the headings of the major themes uncovered in the analysis.

4.2.1. Acquisition Method

The offices from which the quantitative data was collected use a wide variety of acquisition methods for the procurement of construction services. These include sole source negotiated procurements, as well as competitive negotiated procurements utilizing best value trade-off and lowest price technically acceptable selection criteria. In rare instances, these offices utilized sealed bidding procedures which award projects to the lowest priced bidder without evaluating technical capability. Either best value trade-off or lowest price technically acceptable selection criteria is used when issuing competitive task orders.

Based on the interview responses, consensus within a project delivery team typically determine which acquisition method is used for any projects. A variety of factors are used when determining which acquisition method is most appropriate for a project. This decision is usually based on the type of work to be performed, the complexity of the project, the estimated dollar value of that project, the amount of time needed based on the project plan, and the availability of existing contract tools such as existing IDIQ contracts. Most of the interviewees felt that acquisition method directly impacts cost growth and the ability to control cost growth on a project. Unsurprising, negotiated procurements were seen as being better at controlling cost growth because of their ability to ensure that contractors had a clearer understanding of all project requirements.

4.2.2. Contract Type

As expected, based on the quantitative analysis conducted, the contract types utilized by the interviewees were the same as those within the quantitative data sample. The interviewees discussed several factors considered when making a contract type selection decision such as complexity of project, whether the project was within scope of an existing IDIQ, and how quickly the contract needed to be awarded. One interviewee mentioned the need to consider if project items and quantities be could be reasonably estimated and the need to be able to account for that, as well the need to incentivize contractor cost controls. Typically, the contract type selection decision is made concurrently with the acquisition method selection decision. Both of which are made by consensus within the project delivery team.

None of the interviewees had experience using other than firm-fixed price standalone or task orders for awarding or administering construction projects. Several of the interviewees were familiar with the theory behind incentive contracts such as fixed-price incentive firm target and believed there could be value in their utilization. However, the consensus was that government personnel don’t have the skills and/or resources necessary to administer complex contract types. Project delivery teams are hesitant to serve as pilot projects for a non-traditional contract type utilization and most project delivery teams do not consider the possible benefits worth the risk in trying non-traditional contract types. In general, the interviewees felt that firm-fixed price were adequate in handling changes and controlling cost growth during a construction project. One interviewee specifically stated that least cost growth comes from projects awarded using non-competitive task orders with price being determined by RSMeans and a contractor coefficient. This was validated by the quantitative analysis conducted.

4.2.3. Other Common Themes

Along with acquisition method and contract type selection impacting cost growth, other themes were mentioned as potential cost growth factors. One of the most frequently mentioned was that the quality of the project drawings and specifications were seen as a significant contributor to project cost growth. Unclear requirements lead to excessive requests for information, contract modifications and project delays, all of which are known project cost drivers. Another common theme was the impact of fiscal restraints caused by the utilization of federally appropriated dollars. Many times, contractor proposal come in above program amounts which adds additional risk to the project, as all funds must be available at time of award to prevent an Anti-Deficiency Act violation. Federal dollars have finite obligation periods which means if contracts are not awarded before funds expire, the funds will be lost and not be available for obligation. This leads to the extensive use of options as incrementally funding firm-fixed price contracts is typically not allowable by the FAR.

5. Conclusions

The aim of this research was to investigate the impact of contract type selection on cost growth in USACE construction projects. With this aim, a literature review was conducted to investigate various causes for cost growth as well as understand the various contract types allowed by the FAR. Based on the quantitative and qualitative analysis conducted, contract type selection does have an impact on construction cost growth. It can be concluded that negotiated non-competitive task orders and more specifically, those which use RSMeans and a contractor coefficient are best at reducing construction cost growth. In addition, the quantitative analysis showed that the type of work (i.e. MEP repair/replacement, paving, water/sewer upgrade, etc.) impacts the likelihood of project cost growth. Although small business utilization has been seen as a potential cost driver, USACE's utilization of the SBA's 8(a) Business Development Program, has resulted in projects that have less cost growth than other projects.

Based on the interviews it seems that all three contract types within the sample are adequate at handling changes and motivating contractor performance. Although there may be benefits from the use of non-traditional contract types, consensus from the interviewees was that government personnel currently do not have the skills to administer non-traditional contract types, project delivery teams are hesitant to serve as pilot projects for a non-traditional contract type utilization, and organizational cultural does not consider the possible benefits worth the risk in trying non-traditional contract types.

5.1. Research Limitations

Potential limitations of this study include the limited number of projects contained within the sample, as a larger sample size with a broader geographical foot print could potentially impact conclusions found. Additionally, the projects within this sample did not contain large new vertical construction projects. A more in-depth look into the individual cost growth drivers for each of the projects within the sample would provide more detailed analysis than original versus final project costs alone.

5.2. Recommendations

Although competition is known to lead to lower initial pricing, competition in and of itself does not necessarily limit construction cost growth. Working with known contractors to award contracts based upon agreed upon rates and engaging in discussion to truly ensure understanding of project requirements leads to significantly less project cost growth. Based on the quantitative analysis showing that the type of work impacts the likelihood of cost growth, project managers should use this information to mitigate these cost growth risks when possible. Additionally, the 8(a) Business Development Program easily lends itself to establishing relationships with known contractors and awarding sole source contracts under $4 million. Expanding the utilization of RSMeans and a contractor coefficient to larger projects could lead to less cost growth in future projects. Recommendations for further research include a study that looks specifically at contracts that utilize price guide pricing (i.e. RSMeans), the selection criteria used to select theses contractors and the amount of actual negotiations that take place prior to award of a contract. This would help highlight possible reason why some contract types are better at controlling costs than others.

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Cost estimating and building information modelling (BIM) in road construction

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Abstract

BIM (Building information modelling) methodology offers a modern tool for all branches of construction. The information model proceeds throughout the life cycle of the construction work and ideally it contains all the information associated with elements in the model composition. BIM 5D presents another natural step in widening the utilization of information modelling for cost management and which thus puts BIM into practice. The paper deals with the creation of quantity takeoff and budgeting for construction works derived from an information model. Interconnection of theoretical knowledge with building practice has been implemented through cooperation with two multinational construction companies operating in the Czech market. This has concerned cooperation based on putting forward information models which can apply modern technologies for creation of the quantity takeoff and further to budgeting for construction works. Particular study has been carried out on two technically and technologically similar transport projects.

Keywords: BIM; cost; quantity takeoff.

1. Introduction

Building information modelling (BIM) offers a modern tool for solving both technical and economic issues connected with a construction project. The development of information modelling as it relates to cost management has been a widely discussed topic but so far with an almost zero impact on actual practice. The topicality of embedding modern technologies and methods seeking the most efficient way of setting costs for road construction in the Czech Republic (CR) is also supported by ever growing pressure from society for accuracy and transparency on matters of costing for public construction works. In recent years there have been instigated legal claims against high prices and insufficient quality relating to new or modernized road sections. On transport construction projects contractual costs reached overcharge levels amounting to tens of percentage points and indeed there were technical errors leading to the impossibility of using roadways to the full planned intent.

The responsible public body allocating finances for all branches of infrastructure structures is the State Fund for Transportation Infrastructure (SFTI). SFTI has initiated a steady growth of finance flowing into the construction of transport infrastructure from 2015, and there has been so far the biggest increase in monetary expenditure on transportation infrastructure compared to the previous budgetary year- actually by 56 %. In monetary terms, from CZK 23.0 billion to CZK 35.9 billion. This highlighted a revitalization of the construction market in this segment as well as the general economic situation in the Czech Republic. Unfortunately, this trend of construction production growth then stopped, primarily due to the absence of expert opinions on the influences of structures on the living environment and how this affects the possibility of financing projects from EU financial sources. Thus, since 2016

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there has been a steady state financial support from SFTI for road construction, holding below the limit CZK 40 billion per year.

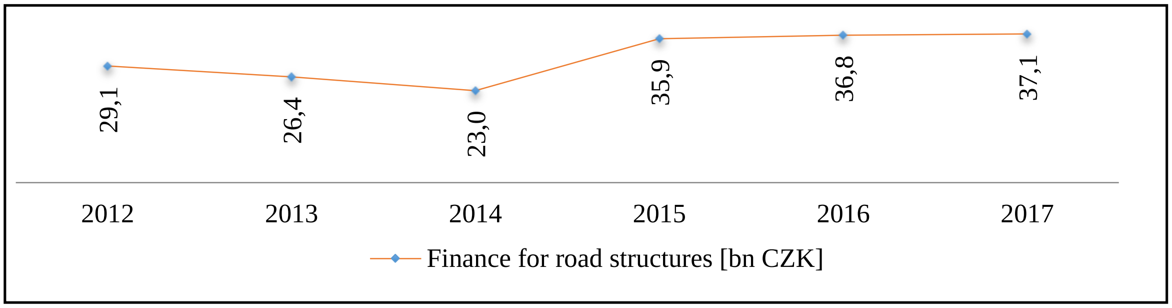

Fig. 1. Financial resources provided from SFTI for the road construction segment [1]

SFTI is integrating BIM into Czech legislation and into the actual process of transport construction. The intention of SFTI is to apply the so-called "good man´s care" principle and integrate the BIM methods to the infrastructure sector in order to achieve higher efficiency. To do so a Plan for digitalization and BIM integration has been prepared by the SFTI. [2] The Czech Government Resolution No. 682 of 25 September 2017 approved the Concept of Implementation of the BIM Method in the Czech Republic, contained in Part III of Material 918/17. This document has been prepared in cooperation with SFTI. Thus the Ministry of Industry and Trade has been entrusted by the Office for Standards, Metrology and Testing (UNMZ) with the prospective intention to use its newly established contributory organization, the Czech Agency for Standardization (CAS), for the implementation of the Government approved measures mentioned in the Concept of Implementation of the BIM Method in the Czech Republic. [3]

The readiness of the construction sector for new modern methods in construction project assignment and procurement will start with testing on three pilot road projects:

- Improvement of a cross-road on roads I/32 and II/125 at the exit 42 of D11 highway – rebuilding into a roundabout;
- D1 Modernization – section 04, EXIT 34 Ostředek – EXIT 41 Šternov – flyover No. D1-040;
- I/42 Brno VMO Žabovřeská I, stage I.

In the view of the public contracting authority, the first structure where the information model (IM) will be used for the selection of the contractor is the building project I/42 in Brno, and the anticipated report on all procedures and work with the information model by both parties (public contracting authority/ contractor) will be made public by the end of 2019.

1.1. Literature review

In recent years the topic of BIM implementation for the construction sector has frequently been raised in scientific journals and publications. Articles usually focus on the general advantages of using information modelling in the life cycle of construction work, with a stress on increasing attention during the design proposal stage where it is possible to significantly influence future costs for repair and maintenance [4,5]. The actual inter-linkage of information modelling to other parts of cost management is a topic unfortunately not that much discussed.

As an example there is the idea to embed BIM 5D in the process of a construction project *„BIM and its allied digital technologies and tools provide enormous opportunities for project cost management professionals to dramatically improve the quality, speed, accuracy, value and sophistication of their cost management services and therein ensure their future as key players in the BIM Word"* where the author states that there must be developed a more determined propagation of the advantages of BIM 5D use in building projects, thus persuading investors to finance this modern technology and require it from a potential project supplier. [6] In the CR the dissemination of BIM is mostly overseen by private sector multinational companies which operate in this market area and they are significantly supported usually by owners in western developed economies who have practical experience with information modelling.

The author Jiang Xu proffers an interesting view of BIM 5D use in construction in the article *Research on Application of BIM 5D Technology in the Central Grand Project.* In the article Jiang Xu focuses on BIM application advantages on the particular project of the Central Grand project. It concerns the description of involving an information model with the process of a real project in a limited form and more likely for secondary impacts. [7] Conclusions of this research are closely monitored for likely possible application in the CR, for example on the above mentioned pilot projects.

Japanese colleagues have done detailed work on BIM use for improving infrastructure project design on design-bid-build contracts. The authors affirm the economic–technical contributions of BIM at different stages of the life cycle with this type of contract. The important conclusion of this work is the necessity of gaining some essential experience before any comprehensive embedding of BIM in the public sector. [8] SFTI has been trying to carry out similar studies applicable to a specifically Czech context but so far with poor results. Public agencies have also been blamed for long term inactivity in this kind of information modelling development.

Another publication deals with a particular part of BIM 5D, namely the automated and semi-automated creation of the quantity takeoff gained from an information model. The main idea of the whole article is „*The current system of estimating price in construction companies is highly labour-intensive and there is much room for error. Making quantity takeoffs from 2D documentation, which is still very common, is obsolete when compared to modern tools.“* The authors present advantages of using modern tools in an information model, compared to traditional 2D techniques. Unfortunately, they failed to establish in actual practice the way to apply generated data from the information model to the creation of the quantity takeoff. [9] A similar topic which concerns taking into consideration local conventions with the creation of the quantity takeoff in connection with BIM 5D, appears the most frequently. Predominantly, authors point to the fact of the impossibility of creating a fully-fledged quantity takeoff from the information model. [10,11]

From the given overview of the professional literature we unfortunately do not perceive an increased interest in the actual creation of the 3D model, where in its graphic and non-graphic detail it significantly influences possibilities of embedding 5D into the whole project process. From our viewpoint this has been caused by the reality that specialists in cost management have not yet fully appreciated the actual creation of the information model with a sense of how the originator sees it, and thus they remain unaware of current possibilities. The article *"Evaluation of Maturity of BIM Tools across Different Software Platforms“* describes these possibilities and assesses different software tools applicable in the BIM context. [12]
Mobile technology has also become a familiar sight on construction sites, "w*ith smart phones and tablets being linked to the Common Data Environment. This access to the coordinated model, drawings and other project documentation improves the quality of work, reducing rework and time spent looking for information. The devices are currently also used to produce paperless quality documentation, carry out site inspections, mark-up drawings and keep site progress records. The move towards paperless documentation has created efficiencies in administrative processes, and also created data that can be used to drive*." [13] In concluding this overview of the professional literature we can state that the BIM method is without exception, the correct way forward in construction activity. Primarily it relates to effective administration of a building project across the life cycle.

2. Assessment of construction production for over-ground road communications – BIM 5D

BIM (Building information modelling) methodology offers a modern tool for all branches of construction. The information model proceeds throughout the life cycle of the construction work and ideally it contains all the information associated with elements in model composition. BIM 5D presents another natural step to widen the utilization of information modelling for cost management and which puts BIM into practice. The possibility of connecting these two professional areas is currently a much discussed topic both with consultancy firms and with contractors. The following fields are of main concern:

- Creation of quantity takeoff;
- Creation of budget for construction works;
- Planning/cost management.

The actual information model is crucial for BIM 5D use. It must be created in such a way as to include necessary graphic and non-graphic information about the elements of which it is composed. The level of detail given in this information is usually defined in the standard documents of the appropriate country or as amendments to contract documentation. The CR unfortunately has no such documents and thus clients prepare their own data standards or have to take up foreign standards. Therefore the publication [14] Level of Development (LOD) is used most frequently. LOD sets out the level of detail in the information model for different phases of project documentation. LOD thus clearly determines which structures and its parts are to be placed in the model and which are not. Besides the information on graphic processing in the model it also defines those that are non-graphic. The non-graphic information is defined in information modelling as the parameters of an element. These, for example, are data for identifying an element, material, volume, area etc. The detail level scale is from LOD 100 (the lowest detail) up to LOD 500 (the highest detail). The documentation for the building permit is at level LOD 300. Each increase in detail level also raises proportionally the demands factor and how long it takes to create an information model. This consequently also influences the cost per model. Also, a problem arising in the Czech market relates to a shortage of experience that project firms have with modelling higher detail levels of individual structures.

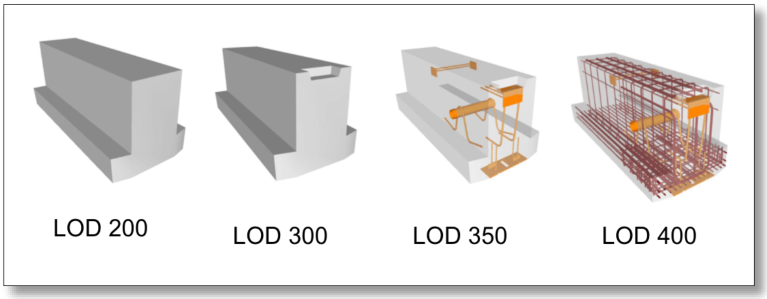

Fig. 2. Graphic representation of detail levels according to LOD [14]

One of the key conditions for the successful interconnection of information modelling and cost management is having an informed specialist with a view of both professional fields in the project team. This fact, according to us, puts a brake on the comprehensive spread of BIM 5D in practice. The given specialist needs to know the current possibilities for creating information models including the supporting software solution and at the same time needs to be aware of demands of the enterprise itself for cost management outputs.

2.1. Quantity takeoff creation and a budget for construction works with the help of an information model

Quantity takeoff creation would be significantly more effective and more accurate with the help of data taken from an information model. Currently, programs on the basis of a BIM environment enable extractions with takeoffs on individual elements, but this information about areas and volumes cannot always be adequately used for all types of constructions.

For clear specification of construction elements in a model and consequent creation of quantity takeoffs, along with requirements according to the LOD methodology, there is also crucial non-graphical data on the classification system of the construction output. The classification system allocates to individual construction activities (elements) an identification code, a description, and a method of setting the quantity takeoff in linkage to the unit of measure. Each country usually has its own national classification system or at least a customary structure of building work classification. However, these traditional quantification workbook structures for building output became unusable for modern work with data. This is why these classic quantification workbooks structures have been replaced in a number of countries by new ones such as e.g. in the UK – Uniclass, the USA – OmniClass or Sweden – CoClass. These modern quantification workbooks on structures enable easier classification of the created elements (structures) and for other possibilities of data processing.

In the CR, where there is a strong involvement of the law on public procurement tenders, and along with this the fact that 90 % of linear structures are commissioned by a public client (who has to be in compliance with this standard), there is no motive to create a modern classification system which would respect the local context of the construction market. At present linear structures are mainly procured through a public client by the existing „classical“ way inspired by principles based on the Red Book (FIDIC). The original idea behind the Red Book is based on the creation of commission documentation, which contains primarily a technical solution to the project documentation by the investor (client). The given commission documentation also contains the quantity takeoff, defined through a classification system identified as a branch quantification workbook on buildings structures and construction works for over ground road communication (OTSKP). OTSKP is a very specific and unique classification system. OTSKP is not well suited to be used for modern demands of information models in this modified form.

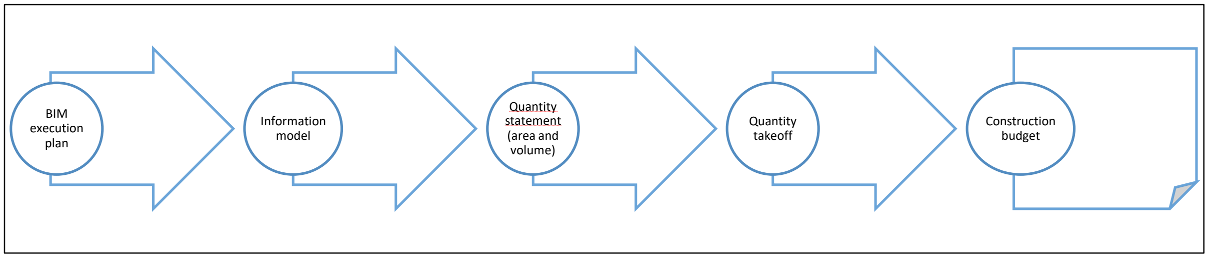

Fig. 3. Scheme of procedure for the creation of a budget of construction works derived from the information model

Fig. 3 shows a method for estimation of a building production. A high quality elaborated BIM execution plan is crucial for the creation of an information model. After creating the information model we take out the information on structures/elements sorted according to the building material with the help of the function quantity takeoff. This extraction will consequently serve as a basis for the creation of quantity takeoffs in the structure of building output classification selected by us. There, after the allocation of building materials to the particular building work (items), we arrive at the quantity takeoffs. Subsequently, the quantity takeoff is brought into software for building production estimation, and there is then reached the allocation of unit and total prices for individual items thus creating a budgetary basis for the construction works.

Even under clearly defined conditions for design managers in the creation of the information model, we will never reach a fully adequate budget of construction works. In order to reach 100 % planned costs from the information model we would also have to include costs which are not directly connected with the project work or information model elements. This would concern cost categories e.g. for deteriorated working conditions, building site installations, other costs etc., where OTSKP has special items for these cost categories. In other countries, these categories of costs are usually broken down into prices for individual building work.

3. Case study of Highway D11 and D1 reconstruction

Interconnection of theoretical knowledge with building practice has been implemented through cooperation with two multinational construction companies operating in the Czech market. This has concerned cooperation based on putting forward information models to apply modern technologies for creation of the quantity takeoff and further to budgeting for construction works. On two technically and technologically similar transport projects in particular studies were carried out. The first is an 8km long reconstruction of the D11 highway from the Prague ring road in the direction of Hradec Králové. This involves the modernization of a highway which includes complete exchange of pavement layers, connecting the interchanges with the Prague ring road, reconstruction of four bridge structures and repair of drainage and utilities. The second project is a reconstruction of the stretch 06 between the exits 49 Psáře and 56 Soutice on the D1 highway 7.7 km in length. It involves again the complete reconstruction of pavement, an extension for additional lanes, a highway bridge reconstruction and flyovers including drainage modernization and vegetation improvements. The case study confined itself only to the building activity shared by both projects, namely the exchange of pavement. Contractors (general suppliers) had the information models elaborated for their costs and for their needs. [15,16]

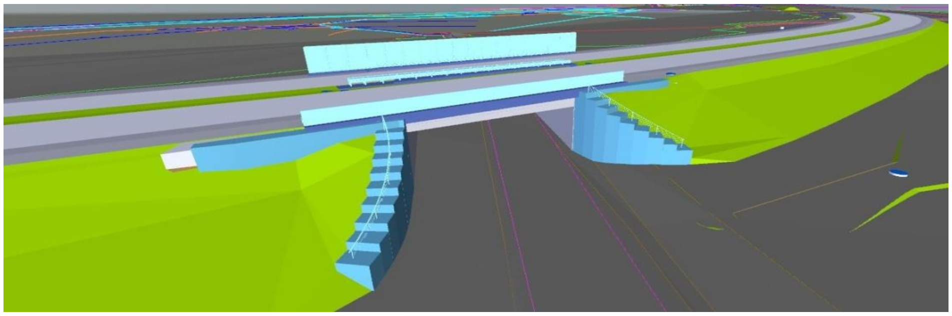

Fig. 4. D11 Highway in the context of BIM

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The use of the information model in both reconstructions is different. With the D11 project the model has been elaborated before starting the building work and serves primarily for quantity takeoffs, survey works, GNSS and UTS heavy machine control systems deployment and quality management and health and safety planning . On the D1 project the information model has been created in the course of the work already started, due to complications on the construction caused by an incorrect elaboration of 2D project documentation. The level of detail for the elaboration of information models complies with LOD 350 standards, and thus also the documentation for the actual carrying out of the construction.

Table 1. Information on the reconstruction of Highways D11 and D1 [15,16]

Highways	D11	D1
Starting	04/2018	03/2016
Ending	09/2019	11/2017
Main route length [m]	8 000	7 700
Winning bid [CZK]	787, 000, 000	929, 000, 000

The scheme shown in Fig. 3 will be used for the creation of the quantity takeoff and budget for the construction works. The first step is getting a report on quantity takeoff from an information model which is subsequently transferred into the quantification workbook structures for road construction OTSKP. The transfer to the conferred information models has to be implemented manually due to the absence of code identification of individual elements as the model originators did not embed this data. By this transfer we will get the quantity takeoff which is put into software for assessing construction production, where there are ranked unit and total prices according to the individual construction work. Thus there will be given a basis for the creation of a budget for all the construction work.

Case study results are shown in Fig. 5. From this we can get information on what percentage of total cost we are able to derive from information models currently present in the construction sector. By aggregation (merging) of building works (items) according to desired building sections (Fig.5) there are created OTSKP (e.g. earthworks, foundation constructions etc.). For example, the percentage value of the construction section on earthworks (Tab. 2) is 42 %. 42 % is the portion of earth works budget we are able to take off from the information model. It follows that 42 % of costs tally with the manually created budget for the construction works. This of course means that 58 % of total costs for the building section earthworks we are simply not able to get from the information model. 3 % is set as a maximum limit of permissible difference between the manual and the generated quantity assessment from the information model. If the percentage difference were higher than 3 %, the value from the information model would be identified as incorrect and it would not be included in the total assessment.

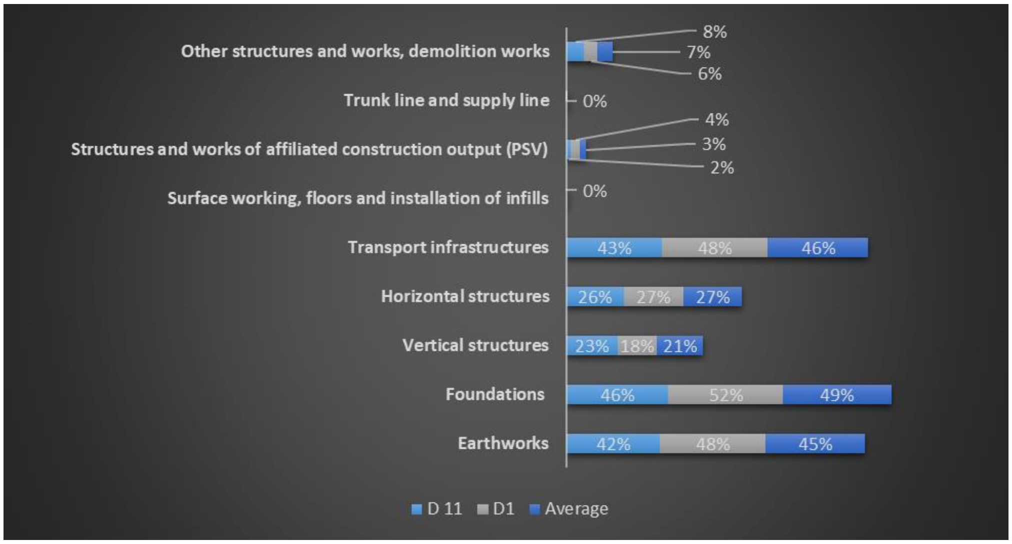

Fig. 5. Result of case study

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Percentage differences between the same construction sections with the Highways D11 and D1 are caused by two factors. The first one is given by the level of detail of the model, despite the fact that both models were in LOD 350 quality. Some constructions were incorrectly drawn and could not be included in the assessment. Furthermore this detail of the model (LOD 350) does not give command in its regulation to draw some elements. Most often these are types of building work involving products used by the ironmonger, plumber and carpenter which are placed in the building section PSV. Building sections with zero percentage value mean that no building activities (items) are used for the highway construction from this section. The building sections for earthworks, foundation constructions and transport infrastructures give very good results. Foundation constructions and road communications contain many items based on volume (concrete, asphalt), and there the quantification from the information model is well achieved. However, in the model for these constructions some elements are absent e.g. formwork which is not drawn into the information model and thus cannot be part of a generated quantity takeoff report. The second factor for the stated difference is caused by minor differences in the work carried out on both highways, even if the projects are similar in terms of pavement reconstruction works.

Table 2. Method of calculating percentage value from total costs for a building section on Highway D11

Building section	Building activity (item)	Quantity takeoff - manual	Quantity takeoff – IM	Total price [CZK]	Percentage value from total costs for a building section
Earthworks	Gravel coarse base thickness 150 mm	1,260 m^2	190 m^3	475, 300	3,80
	Asphalt concrete back coat ACP 22 thickness 60 mm	980 m^2	59 m^3	118, 000	0,95
	Dry hydrate	15,2 t	- (in IM connected with another element)	-	-
	… (next items)	…	…	…	…
	Sum for a building section (earthworks)			5, 264, 700	42,05

The total average percentage value for all building sections is 28 %. This means that we are already capable of getting from the information model data 28 % of the total cost for a construction project. In view of the fact that in the CR information modelling with linkage to cost management is just starting to be formulated, it can be stated that the given findings bring confidence for increased efficiency in budgeting for construction works.

4. Conclusion

Current possibilities for the use of information modelling in the estimation of construction production have been verified in the chapter named Case study of the reconstruction of highways D11 and D1. Information models on reconstruction of highways D11 and D1 are stated as the latest current ones, and these are being used in actual construction and thus they represent the current BIM quality available in the Czech construction market. From the conducted research it has been asserted that with the help of generated data there can be gained on average 28 % of the cost for construction activity. This confirms the increasing level of detail in information models and their subsequent use for further construction segments such as e.g. cost management. Unfortunately, in information models there appeared structural mistakes which made some generated takeoffs unusable. Minor differences also appeared in the level of model processing, where the models were processed by two different Offices, even if they had to be created to the same standard LOD 350. It is supposed that these mistakes will be omitted with the use of a BIM Execution Plan thoroughly specifying rules for quantity take offs.

In information models there has not been used any classification of construction production which would subsequently facilitate work with the extracted data. In the CR, according to the valid legislation for the classification of road construction production, there has to be used the quantification workbook structure OTSKP which, due to its origins in the 1960`s, does not meet modern requirements on data analysis. In order to increase the working efficiency of these information models they must be modified or left aside as has already happened abroad.

The BIM execution plan is the crucial document for the possibility of embedding cost management into information modelling. This document must be created precisely so that the resulting information model can be put to the best possible use. The level of model detail plays a big role here. Given the non-existence of localized Czech standards for BIM, the standards specification usually refers back to foreign specifications LOD where the currently used detail LOD 350 seems optimal from the viewpoint of creating a quantity takeoff/budget for construction works. However, all the regulations determined by this standard must be fulfilled so that there does not arise structural errors and there is no placing together of different materials.

The disadvantage in the CR still lies in the low level of knowledge and awareness on the side of construction companies and design companies regarding the current possibilities for BIM. Broader utilization is limited to willingness to address some potentially considerable investment into software and business analytics. In our national situation it is mostly architects who are working with a model based on 3D models utilizing BIM models to prepare sketches and visualizations. There is usually no further continuation with a primary model created in such a way going towards more detailed levels of project documentation. Companies with multinational operations are driving the change in this environment. The national CR legal situation is weighted against the development of projects based on BIM for use in public procurement tenders, and thus on projects related to transport and road infrastructure. From the clients prospective SFTI is driving the change towards a digital and more efficient environment.

Acknowledgements

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Country Portfolio Model Considering Market Uncertainties in Construction Industry

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Abstract

In recent decades, market uncertainties such as unpredicted economic recessions and expansions have significantly affected to the international construction market. These uncertainties arise simultaneously either at the country level or more broadly and traditional project-based risk management has limited to manage a contractor' profit. From the perspective of managing the market uncertainties, therefore, this study proposes country portfolio model that provides an optimized country portfolio solution through considering on the market outlook, country risk and expected profitability. These are evaluated by country-specific data related construction market and actual project performance data using monte-carlo simulation and genetic algorism. It is expected that the proposed country portfolio model will support to decide better decision about entering new international construction market by giving the ideal country portfolio considering market uncertainties.

Keywords: Country Portfolio; Markrt uncertaity; International constrcution market.

1. Introduction

In recent decades, market uncertainties such as unpredicted economic recessions and expansions have significantly affected to the international construction market. In general, these uncertainties arise simultaneously either at the country level or more broadly [1] (e.g., the Asian financial crisis and the global financial crisis); In addition, since the construction business is an order-based industry, unlike other businesses such as manufacturing, the success or failure of a project is highly influenced by the uncertainties which is caused by characteristics of the host country and its clients. Thus, traditional project-based risk management has limited to manage a contractor's profit [1]. In such rapidly changing and highly uncertain host country environments, diversification is one of the strategic decisions made by international construction firms to manage market uncertainties. There are many studies is conducted the construction market risk and diversification. However, there are still questions about how to manage market uncertainties. Therefore, there is a need to study which is to control market uncertainties through a better country portfolio. The purpose of study is to propose the country portfolio model considering market uncertainties in construction industry by using the monte-carlo simulation and genetic algorithm. This model can provide weight portion of countries among portfolio.

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2. Research Methodology

2.1. Modeling Frameworks

This study proposes country portfolio model that provides an optimized country portfolio solution based on the market outlook, country risk and expected profitability. The market outlook means how the market will change. In this model, it is assessed by construction market's growth rate and volatility of the market size. The country risk means the risk caused by nature of the host country which consists of the political risk, execution risk and institutional risk. it is assessed by the country risk score and volatility of the country risk. The expected profitability means what the profit will be and how the profit will change. it is assessed by the expected profit rate and volatility of profit performance.

The proposed model utilizes a monte-carlo simulation and genetic algorithm. The monte-carlo simulation is utilized to determine the probability distribution of country risk and expected profitability. From the probability distribution, the country risk score, volatility of country risk, expected profit rate and volatility of the profit performance is obtained. The genetic algorithm is utilized to provide an optimized country portfolio solution which is to maximize market growth rate and expected profit rate and while to minimize volatility of the market size, country risk score, volatility of country risk and volatility of profit performance.

2.2. Data Collection

To calculate the market outlook, country risk and expected profitability, this study collects the secondary data on candidate countries and actual project performance data. Country-specific data related construction market were collected from internationally reputable institutions, such as the World Bank [2], IHS Global Insight [3]. The project performance data were obtained from the International Contractors Association of Korea (ICAK) [4] which has information on international project performance of Korean companies. Furthermore, this study selected 14 countries which are United Arab Emirates, Taiwan, Germany, Malaysia, United States, Vietnam, Saudi Arabia, Singapore, UK, Oman, Kuwait, Thailand, Pakistan, Philippines. There are two reasons for choosing these countries. One is that these countries are belonged as main or promising countries in Korea. The other reason is the data availability.

3. The Proposed Country Portfolio Model

3.1. Market Outlook

The market outlook is dealt with how the market will change. It consists the construction market's growth rate and volatility of the market size

The construction market's growth rate means the expected construction spending growth [5]. This study utilizes the forecasted data of the size of each construction market in the Global Construction Database provided by IHS Global Insight [3]. The construction market's growth rate is measured by the compound annual growth rate (CAGR) from 2014–2019.

Volatility of the market size is a concept that is contrary to construction market stability. Volatility of the market size [6] is measured by the percentage of construction market volatility (σ) using IHS Global Insight [3] data for each construction market size over ten years (2007–2016);

$$Volatility(\sigma) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad , \quad (x_i = ln\frac{S_i}{S_{i-1}}) \tag{1}$$

Where S_i = the construction market size at i year,
$\bar{x}$ = average of x_i
and n = the size of the construction market size data set

The construction market's growth rate (CAGR) and volatility of the market size are derived as followed Table 1.

Table 1. Market outlook, Country risk and Expected profitability of candidate countries

Country	Market outlook		Country risk		Expected profitability	
	Growth Rate (CAGE)	Volatility (σ_o)	Risk Score	Volatility (σ_r)	Profit	Volatility (σ_p)
United Arab Emirate (UAE)	0.0779	0.1343	3.0498	0.1776	0.0432	0.1616
Taiwan	0.0778	0.1124	2.4885	0.2001	0.0811	0.1319
Germany	0.0514	0.0762	1.9006	0.0595	0.1088	0.1237
Malaysia	0.0849	0.0846	2.9925	0.1612	0.0371	0.1382
United Stated of America (USA)	0.0799	0.0971	1.9087	0.1475	0.0877	0.1309
Vietnam	0.1226	0.0464	4.6659	0.1212	0.0697	0.1719
Saudi Arabia	0.0769	0.0429	4.1084	0.2623	0.0473	0.1511
Singapore	0.0754	0.1306	1.4703	0.193	0.0303	0.1168
United Kingdom (UK)	0.0879	0.1408	1.5799	0.1084	0.1163	0.1648
Oman	0.0696	0.1353	3.7269	0.1448	0.0314	0.305
Kuwait	0.0307	0.1559	4.4204	0.0899	0.0467	0.1673
Thailand	0.0872	0.0716	3.6077	0.1276	0.0529	0.1462
Pakistan	0.0681	0.0964	5.3658	0.1588	0.0326	0.2541
Philippines	0.0916	0.0929	4.66	0.1981	0.0579	0.1615

3.2. Country Risk

In general, country risk has only been evaluated or considered as a discrete value provided by WGI, DBI, BMI and the other data source. However, when the countries have similar risk levels, it is necessary to evaluate the country by considering the volatility of country risks rather than the subtle risk differences.

To take account of this uncertainty, country risk is calculated with the political risk, executional risk and institutional risk by using monte-carlo simulation. The calculation process is consisted 4 steps.

First step is to calculate the political risk value which explains each country's level of maturity and political stability. It is evaluated by using the worldwide governance indicators (WGI) provided by the World Bank [2]. WGI provide the estimate score (the high estimate score means high quality) and the standard deviation of six factors: voice and accountability; political stability and absence of violence; government effectiveness; regulatory quality; rule of law; and control of corruption. In order to express the uncertainty of political risk, monte-carlo simulation is conducted. The political risk value is derived by summing the probability distributions for each six dimension factors by applying the normal distribution(~n(factor's estimate score, factor's standard deviation)).

Second step is to calculate the executional risk value which explains each country's level of business efficiency and flexibility. This risk is measured by using the doing business indicators provided by the World Bank [2]. It consists ten factors: starting a business; dealing with construction permits; getting electricity; registering property; getting credit; protecting minority investors; paying taxes; trading across borders; enforcing contracts; and resolving insolvency. In order to express the uncertainty of executional risk, monte-carlo simulation is also conducted. However, since DBI don't provide the standard deviation unlike WGI, the probability distribution is derived by data fitting which is fitting the overall distance to frontier (DTF) scores from 2008 – 2017(See Fig. 1). The DTF means the business efficiency and flexibility (the high DTF score means high efficiency). The criterion of choosing the probability distribution is the Akaike Information Criterion(AIC) and subjective opinion based on the form of data set.

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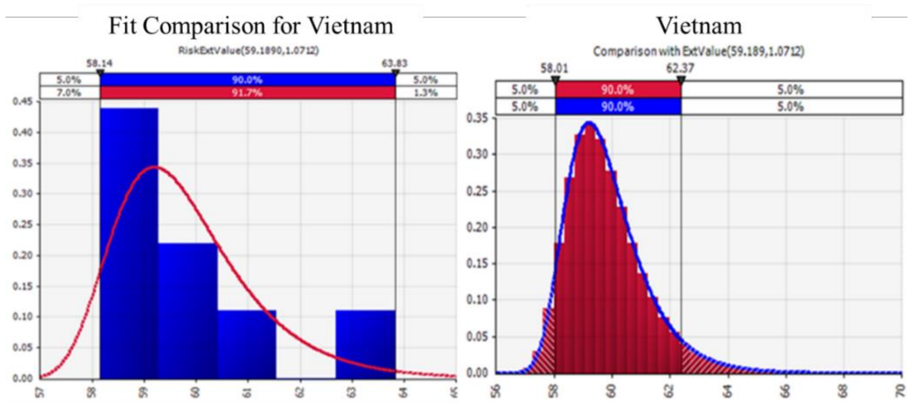

Fig. 1. The probability distribution of Vietnam execution risk value.

Third step is to calculate institutional risk value which explains each country's level of institutional maturity. This risk is measured by using institutional profiles database (IPD). Since there is no data to define the probability distribution, this risk is used the discrete value to calculate the country risk.

Final step is to calculate the country risk value. The country risk value is derived by summing the three risk values which is political, executional and institutional risk values and it is subtracted from 10. The equation as follows:

$$Country\ risk\ value = 10 - (w_p S_p + w_e S_e + w_i S_i) \tag{2}$$

$$w_p + w_p + w_p = 1 \tag{3}$$

Where S_P = value of political risk,
w_p = weight of political risk value
S_e = value of executional risk
w_e = weight of executional risk value
S_i = value of institutional risk
and w_i = weight of institutional risk value

From the country risk value's probability distribution, the country risk score which is the mean of the probability distribution and volatility of the country risk which is the standard deviation of the probability distribution are derived as followed Table 1. (Weight is assumed that the $w_p$is 0.3, $w_p$is 0.6 and $w_p$is 0.1)

As shown in Fig. 2, you can see why considering the volatility is necessary. If decision-maker simply compare the risk scores, Singapore may be a better country than the UK. However, in terms of volatility, the UK is more stable than Singapore because Singapore is more likely to higher risk scores than the UK.

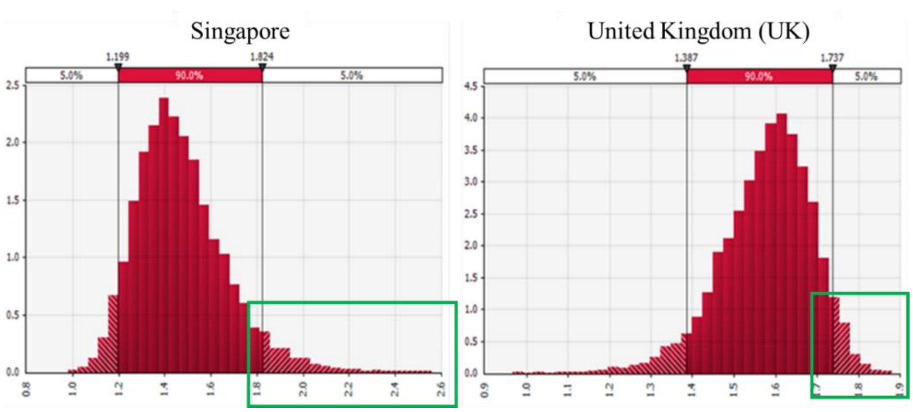

Fig. 2. The country risk probability distribution (Singapore, United Kingdom).

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The sensitivity analysis is also conducted (see Fig. 3). Although sensitivity analysis results were different for each country, in most countries (except Germany, Kuwait), the sensitivity of executional risk is greater than that of political risk. The main reason for this result is that the weight of executional risk is higher than that of political risk. The sensitivity analysis results will change with each weight change.

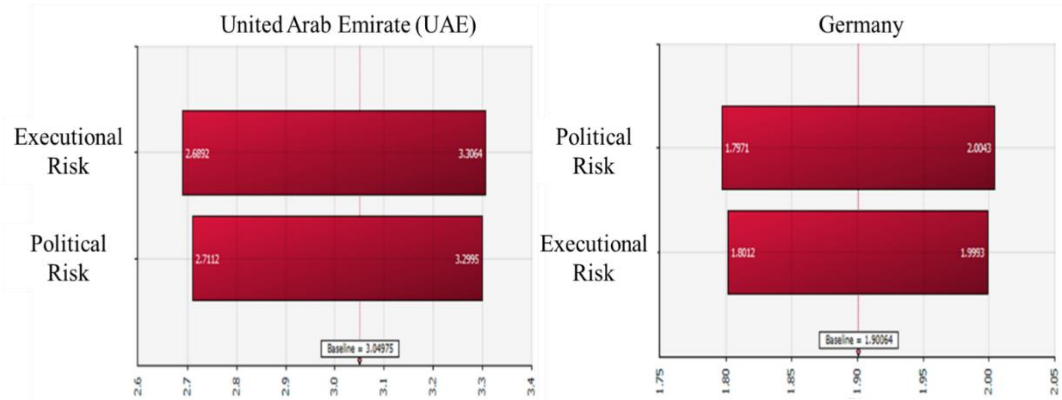

Fig. 3. The result of Sensitivity analysis (UAE, Germany)

3.3. Expected profitability

Expected profitability is measured by using the actual international engineering and construction project profit data [4] executed by Korea contractors across 14 countries over the past 25 years. In order to obtain the expected profit rate and volatility of profit performance, the probability distribution is derived by data fitting (Fig.4). This study removes some data which are too much higher, lower and zero profit rate to improve the Data fitting quality. The criterion of choosing the probability distribution is the Akaike Information Criterion(AIC) and subjective opinion based on the form of data set.

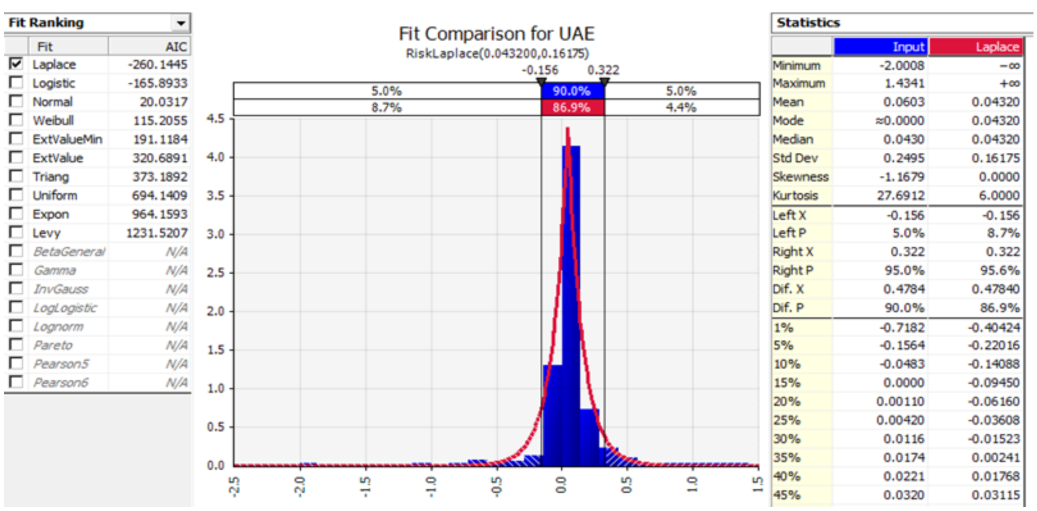

Fig. 4. The probability distribution of UAE profit performance

From this probability distribution, the expected profitability which is the mean of the probability distribution and volatility of project performance which is the standard deviation of the probability distribution are derived as followed Table 1.

3.4. Country portfolio solution from Genetic algorithm

This study develops the objective functions to find the best portfolio solutions that maximize market growth rate and expected profit rate and while to minimize volatility of the market size, country risk score, volatility of country risk and volatility of profit performance.

Before conducting genetic algorithm, this study uses the standard deviation method to calculate variables with the same dimension (standardized score). The standardized score of variable (Z_{V_i}) is calculated as follows:

$$Z_{V_{i,j}} = \frac{V_{i,j} - \mu_{i,j}}{\sigma_{i,j}} \tag{4}$$

Where $V_{i,j}$ = the original value of variable i in country j,
$\mu_{i,j}$ = the average value of variable i in country j,
and $\sigma_{i,j}$ = the standard deviation for variable i in country j.

The objective function as shown in the following equations:

$$Minimize \cdot f(x) = -\sum_{i=1}^{n} x_i Z_{V_{1,i}} + \sum_{i=1}^{n} x_i Z_{V_{2,i}} + \sum_{i=1}^{n} x_i Z_{V_{3,i}} + \sum_{i=1}^{n} x_i Z_{V_{4,i}} - \sum_{i=1}^{n} x_i Z_{V_{5,i}} + \sum_{i=1}^{n} x_i Z_{V_{6,i}} \tag{5}$$

Where f = market portfolios (x)
x_i = weight portion of country i among the portfolios
$Z_{V_{1,i}}$ = The standardized score of market growth rate
$Z_{V_{2,i}}$ = The standardized score of volatility of market size
$Z_{V_{3,i}}$ = The standardized score of country risk score
$Z_{V_{4,i}}$ = The standardized score of volatility of country risk
$Z_{V_{5,i}}$ = The standardized score of expected profit rate
$Z_{V_{6,i}}$ = The standardized score of volatility of profit performance
and n = Number of country

The Constraint conditions as shown in the following equations:

$$\sum_{i=1}^{n} x_i = 1 \tag{6}$$

$$0 \le x_i \le 1 \tag{7}$$

Under these conditions, the genetic algorithm is conducted. This model can find out optimal solution within 70 iterations (see Fig.5) and the weight portion of each country is derived (see Table 2). The result means that if decision-maker want to maximize market growth rate and expected profit rate and while to minimize volatility of the market size, country risk score, volatility of country risk and volatility of profit performance, He or she should allocate highest weight portion of Vietnam among the portfolios.

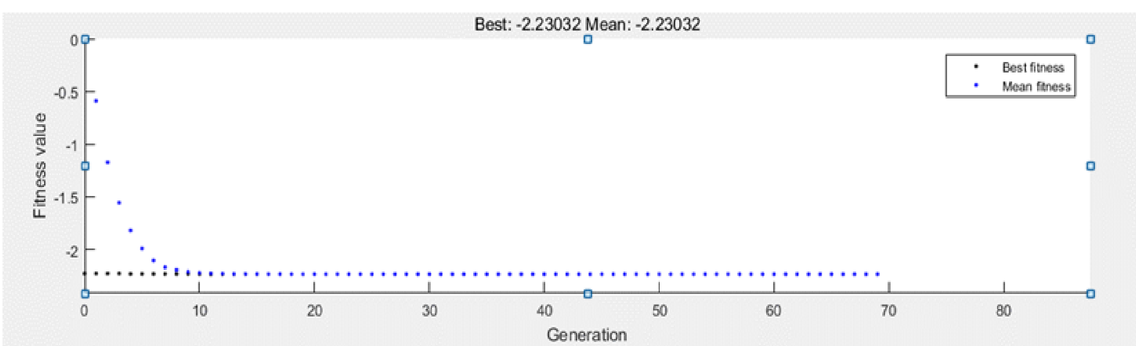

Fig. 5. The result of Genetic Algorithm (plot the fitness value)

Table 2. Weight portion of country among the portfolios

Country	Weight portion
United Arab Emirate (UAE)	0.20%
Taiwan	3.00%
Germany	5.10%
Malaysia	2.90%
United Stated of America (USA)	2.10%
Vietnam	67.70%
Saudi Arabia	2.80%
Singapore	2.40%
United Kingdom (UK)	3.50%
Oman	0.20%
Kuwait	0.00%
Thailand	2.50%
Pakistan	3.50%
Philippines	4.30%

4. Discussion and Conclusion

In rapidly changing and highly uncertain host country environments, diversification is one of the strategic decisions made by international construction firms to manage market uncertainties. From the perspective of managing the market uncertainties, this study proposes country portfolio model that provides an optimized country portfolio solution based on the market outlook, country risk and expected profitability by using monte-carlo simulation and genetic algorithm. The model's final output is weight portion of country among the portfolios. There are some advantages. First advantage is that this model is possible to support decision makers by presenting probability distributions rather than simple discrete values through monte-carlo simulation. Second it model can help to make a more accurate portfolio solution considering the uncertainty of county risk. Furthermore, since it uses accessible data such as WGI, DBI, GI and so on, it has an advantage that it can be easily used by anyone.

However, there are many limitations. The variables to be considered are too few and simple to make a country assessment. For example, competitiveness of order and intensity of competition are very important factors in country assessment, but they do not reflect these. Also, since the model is constructed by relying on general data, it is less usability in practical area. Finally, the objective function and constraint conditions are too simple.

There are a lot of variables and uncertainties which affect the country assessment. In the future study, if a model is developed that can be analyzed by adding unobserved variables such as competitive strength and the characteristics of country such as experience, host government, I think it can be used as a support tool. Also, from the optimization point of view, I think that it can be a good model if a more realistic optimal function and constraint is set.

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Critical leadership factors to enhance workers performance in the South African construction industry

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Abstract

Leadership is known to be linked with construction workers' performance. Literature suggests that construction workers' morale and engagement are boosted by effective leadership. For South African construction industry to play its part effectively in the Gross Domestic Product (GDP) of South Africa, increase in productivity is vital. Hence, to achieve this goal we cannot negate the need for quality leadership among our project leaders and construction professionals. The main objective of this paper is to investigate the critical leadership factors essential for the enhancement of construction workers' performance for effective project delivery in the South African construction industry. The primary research data were collected through the use of a structure questionnaire survey targeted at 81 construction professionals in the Gauteng Province of South Africa. Respondents were selected using purposive sampling technique. Data from the questionnaire were analysed using Statistical Package for the Social Sciences (SPSS) version 22.0 software. Mean values and standard deviation were computed. The ranks of the critical leadership factors to improve workers' performance were established. Findings from the study revealed that effective communication within the project environment and proper planning of work for the workforce are of the optimum importance for performance enhancement and effectiveness. The study also revealed that the enlistment of subordinates in a common vision by appealing to shared aspirations contributes to optimum performance. It further revealed that good dispute management, continual search for innovative ways of improvement, setting exemplary actions by the leader, proper supervision of work, regular meeting with subordinates, and contingent rewards for job well done are all essential for organisational effectiveness and performance enhancement. The study contributes to the body of knowledge on the effects of effective leadership on project delivery and in turn project success in the South African construction industry.

Keywords: Construction industry; leadership, organisational success.

1. Introduction

The construction industry is one of the prime contributors to the modern economy; its relationship with the gross domestic product of a nation is essential [19]. For South African construction industry the reverse is not the case. However, performance wise, the construction industry has its ups and downs by the nature of the work involved and is known for its competitive nature [20]. Effective leadership therefore is a necessity for optimum performance and high productivity. Hence, it is essential to learn what leadership is, and the vital factors for increasing workers' performance [34]. Proper leadership in any organisation helps mitigate wastage of resources especially time, labour and money while upholding quality of work in general [3]. Unfortunately negligence of leadership has done more harm than good because many professionals solely depended on technical skills to get the job done [25,27]. Technical skills although necessary are still not enough for maximum productivity – we need that extra edge called

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leadership. This is because leadership calls for creativity, calculated risk taking, ability to inspire and influence others, as well as winning with people rather than maintaining standards or just meeting targets [18,26].

On another note, leadership means different things to a lot of people and sometimes is misinterpreted with management [18]. There are many leadership books which have tried to argue and answer the questions of good leadership [9,10,23,32] but there has not been a perfect answer for this question [25]. This is because there are numerous overlaps when relating the differences between leadership and management [14]. However, it was argued that leadership is concerned with the necessary skills and practices required to influence subordinates while management is based on the maintenance of standards [26]. Jarad viewed leadership as a subset of management, indicating that both are essential to facilitate organizational performance [18,25]. However it was indicated that real leaders have the capacity to manage but not all managers can lead; hence, leadership is a plus to management [26,32]. Another characteristic of good leaders from literature is the ability to have a clear cut idea and the persistence to see the manifestation of it amid challenges and failures [24]. In addition, leadership calls for the involvement of all the team members to the attainment of the set goals [10,34]. Real leaders primarily focus on what they can contribute rather than what they will get and when this scenario is in place, many things will fall in place [9,10]. In this 21 century, construction professionals need to possess robust leadership skills to effectively lead themselves and their subordinates [18,33]. Finally, with proper leadership, challenges like slowness in adapting to change, unpreparedness to uncertain future, and inappropriate implementation of strategic planning can be mitigated [24,34]. To this effect, this paper investigates the critical leadership factors essential to enhance workers' performance in the South African construction industry.

2. Leadership defined

Munroe [29] defined leadership as "the capacity to influence others through inspiration motivated by a passion, generated by a vision, produced by a conviction, ignited by a purpose". Hence, leadership is an act of giving meaningful purpose and direction which in turn causes positive response towards actualising of a desired goal [17]. For Burns [6] leadership is the process of mobilizing resources to trigger desire for accomplishment as well as satisfy the needs and intents of the subordinates. However, it is good to understand that although leadership may start with a position, leadership is not a position, but the capacity to influence others [26]. A leader should have the capacity to envisage a future event; aligns people with that vision and motivates them to actualise the desired goal irrespective of challenges [22]. Fiol et al. [11] further affirmed that leadership is the capacity to motivate people with the aim of contributing to the success and effectiveness of the organisation. This is evident in our everyday life where we see people in positions but does not have the capacity to influence others; thus, fall short of the goal of the organisation. Good leaders empower others to make decisions [15]. Hence, to empower others, there should be a relationship in place [23]. Therefore, leadership can be summed up as an interaction between the people who opt to lead and that react as follower [24,29]. The subordinates choose to follow because, trapped in every follower is a leader [29]. In other words, leadership ability can be developed in every individual [26,27]. Kouzes and Posner [23] also understood this concept, as they defined leadership as a process of bringing forth the best from an individual and others.

2.1 Essential leadership factors for enhancing workers' performance

In a complex environment like that of construction where people are required to work together, deal with project pressures and meet targets, leadership challenge therefore becomes unavoidable [24,31,34]. Hence, it is necessary to have strong and exemplary leaders [24]. Although all leaders have a unique signature strength which lets them succeeds in the right context [25], there are essential factors that help enhance performance and effectiveness of an organisation [12,23]. Toor and Ofori [38] noted that leadership disposition includes factors such as personal traits, ability to give clear information and the know-how of situational variables in operation. Hence, leaders are required to build on their strengths; work around areas of weakness for continual improvement [26]. In addition, leadership is a team sport; there is nothing like a lone hero; therefore, a leader is required to work with others who have strengths which will compensate for the gaps [32].

Effective leaders make a difference; they do not accept the status quo [26,29]. They move others and themselves beyond their comfort zones towards actualising the organisational objectives [26]. Effective leaders identify their context; the ability to discover where one can utilise to the best advantage is essential for success [24,38]. An effective leader's aim is to provide support to his/her subordinates or set in place all the necessities for the attainment

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of the set goals [2]. Hence, the essential leadership factors for the enhancement of workers' performance are expounded below.

- Effective communication

Effective communication can help group members to follow through with the given instructions [13]. The key to effective communication is simplicity. Hence, an effective leader distributes information and ideas in a clear and concise manner for easy grasp of what is passed across [7]. In addition, it is important to incorporate emotional intelligence while communicating with subordinates [8].

- Proper Planning

A strategic leader provides a clear goal, set direction and systematic plans for the attainment of that goal [34]. The value of planning and strategic capability is tremendous if any goal is to be achieved. Proper planning will help people know what to do, when and how to do it. The leader should be able to make use of various types of plan such as strategic plans, contingency plans, tactical and operational plans [4].

- Shared Vision

Visioning can be defined as a process which is categorised in phases such as the creation stage, improvement stage as well as the renewal stage of the vision [18]. Vision is everything for a leader because it fuels the fire within which helps draw the leader and the subordinates forward [18,36]. Involving people in decision making even when the leader already knows what to do can create a sense of importance and recognition among subordinates [12,24].

- Good dispute management

The ability to limit the negative aspects of conflict in each situation and seek out beneficial ways to cope with the unexpected changes is required in the management of projects [30]. A good project leader ensures that tensions and conflicts are minimised in the organisation.

- Innovative/Initiative

A leader should be on the creative side of events and not on the reactive side [1,18]. Successful leaders keep moving forward and are not complacent; they make things happen and are not afraid of failure [24]. They look out for opportunities and innovative ways to improve and this attitude is a positive influence to the subordinates [24].

- Team building

No man is an island. The bigger the dream the more competent team and collaborative effort required [21]. Hence, good leaders build trust and facilitate relationships to promote collaboration [21]. In addition the leader must ensure that below par performance from any of the team members is addressed on time so that it will not affect the efficiency of the group [27]

- Setting good example

Workers are motivated when the leader clarifies values and procedures as well as align their actions with the shared values [23, 24]. Actions they say, speak better than words. Hence, being a role model and setting good exemplary attitude is likely to create a positive influence on the subordinates' performance and on the organisation [34].

- Supervision

The leader should make his/her acquired skills to instruct and guide the subordinates to ensuring that they conform to project requirement [30]. He/She may systematically evaluate his subordinates based on their strengths and weakness as this may help reconcile any conflict of interest that may arise among the team members [33].

- Inspirational leadership

Leaders utilise their energy towards inspiring people to exercise creativity in solving problems [5]. Zalenik affirmed that the need to maintain order and standards which is driven by management can sometimes stampede the creativity of a leader [39]. He also states that while managers tend to avoid risk, leaders on the other hand, seek them out and act [39].

- Regular meetings

Leadership is acquainted with actions that are principal in mobilizing another action for organisational success such as the presiding of meetings by the leaders [37]. Hence, regular discussions and meetings with workers about their pending targets will ensure that they follow through to their commitments and this will help their accountability [37].

- Contingent rewards

Here the leaders aid in exchange for the effort given and offer recognition for the attainment of the set goals [3]. Good leaders are quick to show appreciation for any outstanding performance from their subordinates and are fair in the rewarding of subordinates [26].

3. Research methodology

This research adopted a quantitative approach which involved the use of a questionnaire. Quantitative research is a survey to obtain information from a sample of people by means of self-report from respondents by a sequence of questions posed to them by the researcher [16]. It is one of the cost-effective ways to collect data from many respondents [27]. Hence, 5-point Likert-scale survey questionnaire was constructed from the detailed literature review. Weights were assigned to each response ranging from 1 to 5 from “strongly disagree” to “strongly agree”. A purposive sampling was used, targeted at 81 construction professionals in the Gauteng Province of South Africa. 63% response rate was achieved. The professionals were limited to project managers, architects, quantity surveyors, construction managers, civil engineers and town planners. Data were analysed using the Statistical Package for Social Sciences (SPSS) version 22.0 software. The reliability and internal consistency of the collected data were appraised using Cronbach’s alpha α. The α value for the leadership factors to enhance workers’ performance were 0.81. Mean (M) and standard deviation (SD) values were used as output. Finally the rankings of the critical leadership factors used by the various construction professionals to enhance workers’ performance were assessed base on the mean values.

4. Findings and discussions

The findings centred on the various leadership factors for performance enhancement from literature. Results according to table 1 revealed that *effective communication* within the project environment is of the optimum importance having the best ranking of mean (4.50) and standard deviation (0.58). It was followed by *proper planning* of work for the workforce. (M=4.50, SD=0.61, R=1). Other results and their rankings were as follows: enlisting others in a common vision by appealing to shared aspirations (M=4.44, SD=0.61, R=3); good disputes management skill by the leader (M=4.40; SD=0.78; R=4); continual search for opportunities and innovative ways to improve (M=4.34, SD=0.67, R=5); creating team building opportunities for employees and facilitating good relationship are essential (MS=4.34, SD, 0.69, R=6); setting good example by aligning actions with the shared values has a positive impact of workers’ performance (M=4.28, SD=0.73, R=7); adequate guidance and supervision (MS=4.18, SD=0.66, R=8); inspirational leadership is important within a project environment (MS=4.14, SD=0.97, R=9); regular discussion and meetings with workers about their pending targets (MS=4.12, SD=0.87, R=10); and contingent rewarding of workers (MS=4.02, SD=0.82, R=11).The fact the all the mean of the above statements exceeds the 3.0 out 5.0 scale is a vital proof that all construction professionals agree with these factors from their own experiences in the construction industry.

Findings from this study support the five practices of exemplary leadership for organisational performance enhancement which are: modelling the way, inspiring a shared vision, challenging the process, enabling others to act and encouraging the heart [12,23]. Hence, the factors from this study are essential for the leadership challenge of improving subordinates and organisational performance especially that of the South African construction industry.

Table 1 Critical leadership factors toward workers' performance in the South African construction industry

Critical factors	Mean	Standard deviation	Rank
Effective communication within the project environment	4.50	0.58	1
Proper planning of work for the workforce	4.50	0.61	1
Enlisting others in a common vision by appealing to shared aspirations	4.44	0.61	3
Good disputes management skills by the leadership	4.40	0.78	4
Continual search for opportunities and innovative ways to improve performance	4.38	0.67	5
Creating team building opportunities for employees and facilitating good relationship	4.34	0.69	6
Setting good example by aligning actions with shared values	4.28	0.73	7
Adequate supervision and guidance	4.18	0.66	8
Inspirational leadership	4.14	0.97	9
Regular discussions and meetings	4.12	0.87	10
Contingent rewarding of workers	4.02	0.82	11

5. Conclusions

The study set out to establish the essential leadership factors for workers' performance enhancement in the South African construction industry. Leadership was defined and its importance for organisational success was also emphasised. Findings revealed that effective communication within the project environment and proper planning of work for the workforce are of the optimum importance for performance enhancement and effectiveness. It also revealed that the enlistment of subordinates in a common vision by appealing to shared aspirations contributes to optimum performance. It further revealed that good dispute management, continual search for innovative ways of improvement, setting exemplary actions by the leader, proper supervision of work, regular meeting with subordinates, and contingent rewards for job well done are all essential for organisational effectiveness and performance enhancement. The study provides useful insight to develop measures to improve construction workers' performance which will in turn mitigate project delays, and decrease cost overruns. Hence, appropriate implementation of these factors will do more good than harm to the overall productivity of the South African construction industry.

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Design rules to improve efficiency in the steel construction industry

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Abstract

In steel construction projects, 88% of total decisions impacting cost are made during the design phase. These decisions are made by design professionals, who have neither the knowledge nor the experience of manufacturing operations. In manufacturing engineering, collaboration between designers and manufacturers is well established and formalized through different methods and design rules such as design for manufacturing and assembly (DFMA). These rules provide designers with essential knowledge to reduce the cost and time of manufacturing and assembly of parts during their design, while increasing customer satisfaction
Building Information Modeling (BIM) and TFV Theory (Transformation Flow and Value) provide to the construction industry, tools and processes to improve collaboration between design and manufacturing phases while reducing waste during projects. However, BIM and TFV theory do not formalize collaboration between designers and manufacturers of steel structures. Yet, the lack of collaboration between these two phases causes lot of rework, lot of waste of time and material during projects.
The aim this research is to develop design rules to overcome some of these issues. These rules use the information taken from the BIM model of 1000 steel structures from a steel manufacturer, to reduce the manufacturing time. These information are grouped and classified according to criteria evaluated using a neural network algorithm. In addition, the recent integration of artificial intelligence in construction projects provides industry with methods to draw from previous projects, essential knowledge for better decision-making. The research shows the strong dependence of the manufacturing time of the steel structures on the quantities of complete cuts and weld in full penetration and on the number of beams that do not come in right angles in the connections.

Keywords: Building-information-modelin; Design-rules; Neural-network-algorithm; Transformation-Flow-Value;

1. Introduction

Here 88% of total time and cost decisions for steel structures are made during the design phase [1]. However, in traditional processes (linear and fragmented) the manufacturer (third party of the subcontractors) is at the bottom of the supply chain: he has no opportunity for interactions with the design professionals to improve the design solutions considering the capabilities' of the manufacturer [2,3]. This situation causes a sub-optimal design that does not take into account the components and manufacturing constraints [4,5], resulting in increased cost and delays in steel construction projects [6]. In manufacturing engineering, collaboration between designers and manufacturers is well established and formalized through different methods and design rules such as design for manufacturing and assembly (DFMA) [7]. The DFMA acts directly on the cost and the time of realization of products by proposing up to 57% reduction of the time of manufacture and assembling, 68% of customers satisfaction and 51% reduction of the number of parts [8]. These rules provide designers with essential knowledge to reduce the cost and time of manufacturing and assembly of parts during their design, while increasing customer satisfaction [9]. We argue that, such design rules can be formulated and applied in steel construction projects, as a way to improve the efficiency and efficacy of the fabrication and installation of steel components. BIM brings to the construction industry, tools and processes that could

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facilitate collaboration between designers and manufacturers [10]. In steel construction, BIM is mostly used for constructability, and for quantitative estimation of structures [11]. BIM is not yet used to its high potential because it does not promote the integration of production practices with designers [12]. There is an opportunity to leverage BIM benefits by introducing new procurement approaches that permits this dialogue between designers and manufacturer, bringing the later at the front-end of the design process. However, this requires drastic changes in industry practices. The development of design rules is seen as a middle road to make available manufacturer knowledge to the design process. Design rules are closely related to the current production process [13]. In steel construction, the capability of production differ from one workshop to another. It is therefore necessary to identify the time indicators in production processes, which will inspire the establishment of design rules. Unfortunately, traditional estimation methods do not do enough, and artificial intelligence (AI) is increasingly being suggested to predict costs in construction industry and to describe the processes of production [14]. AI is increasingly used for predicting the manufacturing time of steel structures [14]. AI techniques make it possible to search and organize data from previous projects according to the variables that influence the time of realization of projects. The algorithms will be inspired by these data to predict with a good accuracy, the times of realization of future projects [15]. These data can be provided through BIM models. The research objective is to propose, design rules focusing on a particular production process that influence the time of realization of projects. To achieve this, the BIM models of 1000 steel structures will be analyzed and classified according to predefined variables. The weights of the variables will be established and design rules will be proposed according to the weight of the selected variables.

2. Related work

This section presents these key points related to this study: the use of BIM models as data sources, the establishment of a prediction to find the weight of the variables that influence the manufacturing time and the development of design rules

2.1. BIM models as data sources

Monteiro (2013) and Shen (2010) propose to use BIM data as sources for prediction. BIM offers the possibility of adapting BIM models to extract data according to estimation criteria [16]. Integrating BIM models into project cost and time estimating processes produces better results than traditional methods [17]. BIM also offer the possibility of introducing information related to the manufacturing of steel structures in design process [18], in order to build a database, which will be used to estimate the cost and time of project. Data extraction can be done automatically from the model, in order to plan and control phases [19,20].

2.2. Prediction of manufacturing time for project steel components

- Choice of algorithm

Several authors suggest to use the neural network as prediction algorithm in steel construction [21-24]. The application of neural network has many advantages for prediction. Among its advantages: his speed of execution, its ability to generalize results and insensitivity to data noise and the capability to undertake into account complex prediction cases with several variables [25]. The use of neural network in the prediction of steel structures offers effective results with errors ranging from 4.63% to 16% [26]. However, neural networks require many resources to function and present results that are difficult or impossible to interpret [27]. This study will use the neuron network as the algorithm.

One of the most important steps in estimating project completion time is the selection of variables or estimation factors. The selection of these variables should be done in a way to avoid errors and over-processing. Table 1 proposes variables used by some authors, for estimating the cost of steel construction.

Table 1. Variables proposed by the authors.

Authors	Variables	units
Mohsenijam & Lu (2016)	steel weight	ton
	the complete penetration weld	m
	the hex type bolt	number
	the I-beam	m
	the round hollow steel section	m
Sarma & Adeli (2000)	the geographic localisation	position
	the number of connections	number
	weight of rolled sections	kg
	different section types used in the structure	number
	the cost of rolled sections	$
Hu et al. (2014)	…	
	the length of the types of profiles used	m
	the length of complete fusion weld	m
	the length of partial fusion welds	m

According to these authors (table 1), the estimation variables are circumscribed by masses, length and quantities of the elements of the steel structures, which could be extracted from the BIM models database. However, criteria such as the volume of the structure, the number of cuts, the number of holes, and the length of preparation of the steel structures are not considered. Yet these criteria directly influence the duration and cost of manufacturing [28].

2.3. Development of design rules

In the manufacturing industry, DFMA is a method to help reduce the cost and duration of realization of the products by reducing the quantities of elements, the complex operations, the manual operations, and by simplifying the structure of the products [29]. Construction activities are like a manufacturing process [30], especially in steel construction. However, variables related to transport, maintenance, technical assistance, use of standard tools and materials can also influence the cost of the product [9]. Variables related to product structure and machining operations are therefore essential to the development of design rules.

 DOI 10.3311/CCC2018-056

3. Research method

The method for this research to develop design rules is divided in 3 (three) steps (figure 1). These steps are: harvesting and data mining, predicting manufacturing time and determination of variable weights, designing rules for steel structures.

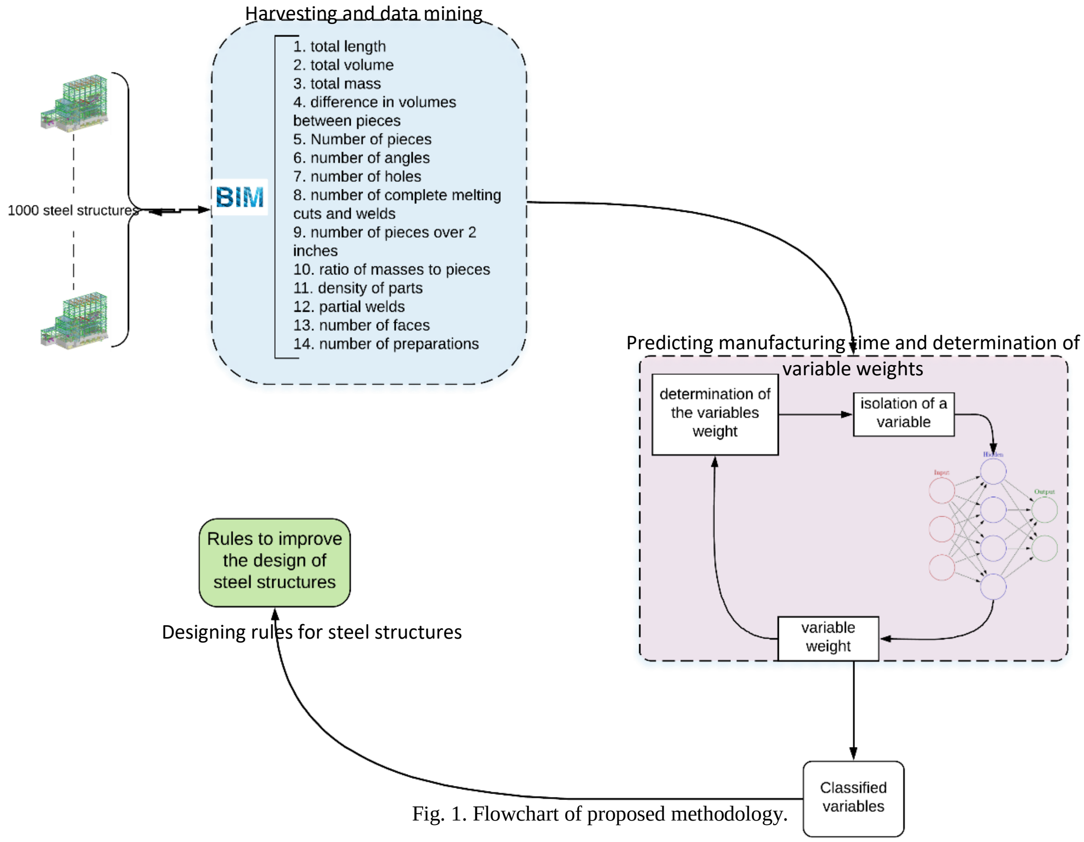

Fig. 1. Flowchart of proposed methodology.

3.1. Harvesting and data mining

In this step, the data come from BIM models (Tekla structure 21.0), organized according to the selected criteria, which take into account the factors that influence the duration of the fabrication of steel structural elements. For better results in prediction using neural networks, normalized variables data is required [27]. Normalized variable data means: reduce the variable to values ranging from 0 to 1. To do this, Equation (1) is used.

$$function(x) = ((x - \min(x)))/((\max(x) - \min(x))) \quad (1)$$

3.2. Predict manufacturing time and determination of variable weights

To better compare the results of a prediction with the real data, Lantz (2015) proposes to calculate the following values: The correlation (Cor), the Mean absolute error (MAE) and the relative absolute error (RAE).

Correlation
$$Cor = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{(n-1)\, S_x S_y} \quad (2)$$

Mean absolute error
$$MAE = \frac{1}{N}\sum_{i=1}^{N}|\bar{x}_i - x_i| \quad (3)$$

Relative absolute error
$$RAE = \frac{\sum_{i=1}^{N}|\bar{x}_i - x_i|}{\sum_{i=1}^{N}|\bar{x} - x_i|} \quad (4)$$

Where $\overline{x_i}$ is a mean value of x_i and $\overline{y_i}$ is a mean value of y_i

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The algorithm will perform several predictions with each time, a variable less, to find the weight of the variables involved in the prediction.

3.3. Design rules for steel structures.

Through predictions, variables now have weight. Based on these weights, the study will propose instructions to be considered during the design phase of the steel structures, to reduce the manufacturing time of the elements. These instructions will define our design rules.

4. Results and interpretations

Table 2 presents the results of the prediction.

Table 2. fabrication time prediction results.

results	*variables*	*correlation*	*MAE*	*RAE*
R all	all variables	0,9841005410	0,0083005274	0,1725046537
R1	1. total length	0,9214258619	0,0847322012	1,2711706370
R2	2. total volume	0,5068106424	0,2392389322	1,3994818300
R3	3. total mass	0,9668307042	0,0516198343	0,7267404529
R4	4. difference in volumes between pieces	0,9685086988	0,0466218118	0,6623405512
R5	5. number of pieces	0,4423277468	0,2552932616	2,4596952140
R6	6. number of angles	0,4423277468	0,2552932616	2,4596952140
R7	7. number of holes	0,9659978485	0,0202921947	0,3692790984
R8	8. number of complete melting cuts and welds	-0,1787795600	0,4941618021	2,4027818090
R9	9. number of pieces over 2 inches	0,8678071094	0,1150959974	2,8127183850
R10	10. ratio of masses to pieces	0,9739915642	0,0251589375	0,4168327297
R11	11. density of parts	0,9608203939	0,0141813740	0,2597240733
R12	12. partial welds	0,9518767118	0,0118450157	0,2220511256
R13	13. number of faces	0,9816932789	0,0096399970	0,1925543997
R14	14. number of preparations	0,9849647839	0,0090870625	0,1870279812

In (R all) are the results that imply all the variables: "R all" corresponds to: 98.4% correlation coefficient, and 17% Relative absolute error with 0.8% of Mean absolute error. The predictions made with variable substitution give us the results from R1 (results without variable 1) to R14 (results without variables 14).

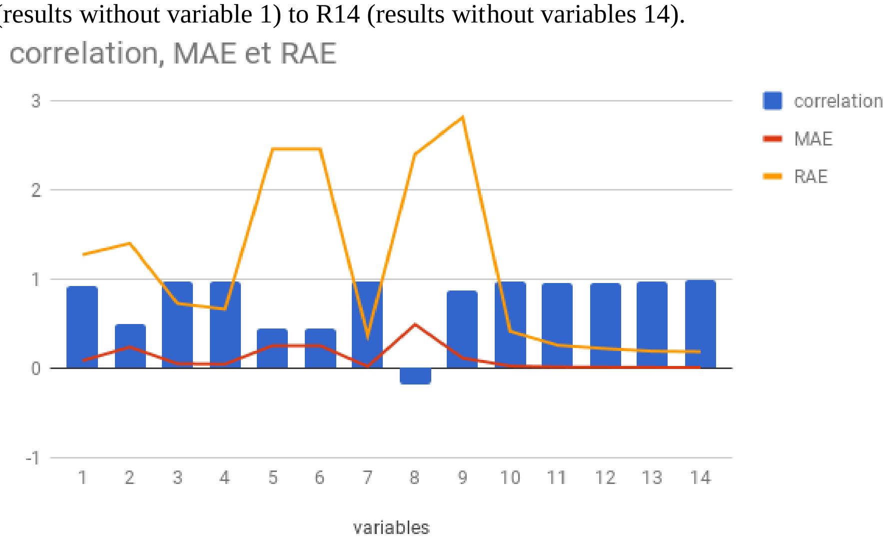

Fig. 2. summary of correlation calculations and errors.

Through these predictions, the variables are classified according to the influence that their absence causes in the accuracy of the algorithm on the Cor, the MAE and the RAE

results	variables	correlation
R14	14. number of preparations	0,9849647839
R13	13. number of faces	0,9816932789
R10	10. ratio of masses to pieces	0,9739915642
R4	4. difference in volumes between pieces	0,9685086988
R3	3. total mass	0,9668307042
R7	7. number of holes	0,9659978485
R11	11. density of parts	0,9608203939
R12	12. partial welds	0,9518767118
R1	1. total length	0,9214258619
R9	9. number of pieces over 2 inches	0,8678071094
R2	2. total volume	0,5068106424
R5	5. number of pieces	0,4423277468
R6	6. number of angles	0,4423277468
R8	8. number of complete melting cuts and welds	-0,1787795600

Fig. 3. impact of the variables on the correlation coefficient.

results	variables	MAE
R14	14. number of preparations	0,0090870625
R13	13. number of faces	0,0096399970
R12	12. partial welds	0,0118450157
R11	11. density of parts	0,0141813740
R7	7. number of holes	0,0202921947
R10	10. ratio of masses to pieces	0,0251589375
R4	4. difference in volumes between pieces	0,0466218118
R3	3. total mass	0,0516198343
R1	1. total length	0,0847322012
R9	9. number of pieces over 2 inches	0,1150959974
R2	2. total volume	0,2392389322
R5	5. number of pieces	0,2552932616
R6	6. number of angles	0,2552932616
R8	8. number of complete melting cuts and welds	0,4941618021

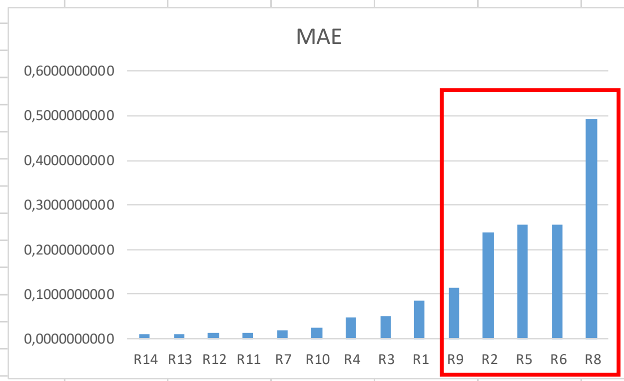

Fig. 4. impact of the variables on the Mean absolute error.

results	variables	RAE
R14	14. number of preparations	0,1870279812
R13	13. number of faces	0,1925543997
R12	12. partial welds	0,2220511256
R11	11. density of parts	0,2597240733
R7	7. number of holes	0,3692790984
R10	10. ratio of masses to pieces	0,4168327297
R4	4. difference in volumes between pieces	0,6623405512
R3	3. total mass	0,7267404529
R1	1. total length	1,2711706370
R2	2. total volume	1,3994818300
R8	8. number of complete melting cuts and welds	2,4027818090
R5	5. number of pieces	2,4596952140
R6	6. number of angles	2,4596952140
R9	9. number of pieces over 2 inches	2,8127183850

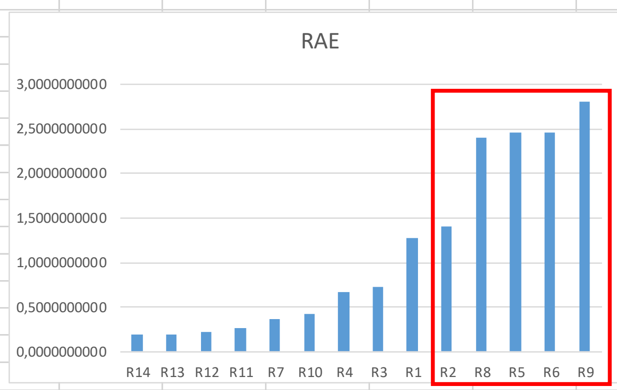

Fig. 5. impact of the variables on the Relative absolute error.

These data present the most influential variables that are:
R8: the number of complete melting cuts and welds,
R6: number of pieces that come in angles.

R5: number of pieces,
R2: total volume,
R9: number of pieces over 2 inches

5. Development of design rules

From the analysis of these results, the following major design lines are proposed:

- Avoid designing structures having many full fusion welds.
- Avoid designing structures with a very large number of parts.
- favor the connection in right angles.
- Avoid designing assemblies with large volume,
- Avoid designing works with thick pieces.

6. Conclusion

This work proposes design rules to reduce the machining time of steel structures. To achieve this, this study collected and organized information from 1000 BIM models of steel structures. An algorithm based on the neuron network made it possible to make predictions of manufacturing time of the structures. This algorithm allowed the classification of the variables according to their impact on the time of realization of projects. The study has formulated design rules to reduce the manufacturing time of steel structures. A working perspective for this study will be to apply these design rules to the design of new projects to be realized in these same workshops, in order to appreciate the impact of these rules on the manufacturing time of the structures.

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Detection of Unbalanced Bids: A Case Study

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Abstract

An unbalanced bid can be defined as a bid price that does not accurately reflect reasonable cost, contractor's profit, general overhead cost and other indirect costs. Selecting an unbalanced bidder as the contractor may lead to significant increases in the contract price. Therefore, detecting the unbalanced bids is a critical issue for owners. There are two main types of unbalanced bid, which consists of front-end loaded and quantity error exploitation. This study mainly focuses on the second type, namely quantity error exploitation, in which a contractor tends to increase the unit prices of items that are underestimated and reduce the unit prices of items that are overestimated because of errors in the estimated quantities. If an owner can detect the unbalanced bids during the awarding stage, a fair competition environment can be achieved. This study aims to provide owners with a model, which may assist them in detecting unbalanced bids. The proposed model uses five different grading systems. Owners may assign different weights to these grading systems and thereby the final score of each bidder can be calculated. All bidders can be evaluated based on the calculated final scores as well as the offered bid prices. The applicability of the proposed approach is demonstrated in an illustrative example. The findings of this study revealed that the proposed approach can be a useful tool for owners in detecting unbalanced bids.

Keywords: Unbalanced bid; detection model; grading system; owner; case study.

1. Introduction

Design-Bid-Build is the oldest, most familiar and traditional project delivery system in the construction industry. Although various alternatives (e.g., Design-Build, Professional Construction Management, etc.) to this project delivery system have been developed, it is still most commonly preferred by a great number of owners, particularly in the public sector. Construction projects built according to this project delivery system mainly undergoes five sequential phases: 1) pre-design phase, 2) design phase, 3) bid and award phase, 4) construction phase, and 5) post construction phase. In the bid and award phase, the owners aim to select the most appropriate contractors, who are capable of completing the project in budget, on time and at desired quality [1]. Therefore, this phase plays a key role in the project success.

One of the ways of gaining unfair competitive advantage against the rivals is proposing an unbalanced bid. Unbalanced bidding can be defined as manipulating the price of bid items without affecting the total bid price. Unbalanced bids are classified into two main categories, which include: 1) front-end loaded, and 2) quantity error exploitation. Front-end loaded unbalanced bidding has two types; front loading and end loading. Front-loading is the most common way to unbalance a bid. Front-loading refers to increasing unit prices of activities that need to be completed at the early stages in order to improve the contractor’s cash-in flow, while decreasing unit prices of activities that are to be completed in the later stages. End-loading is defined by inflating unit prices of late schedule activities. End-loading is used by some bidders to take advantage of escalation clauses in contracts. In quantity error exploitation, a bidder tends to increase unit prices of activities in which actual quantities are expected to exceed the estimated ones, whereas decrease unit prices of activities that are overestimated due to an error in estimated quantities stated in bid documents [2,3].

Unbalanced bidding is a commonly preferred strategy in unit price and lump sum contracts. In unit price contracts, unbalanced bids can be done by manipulating unit prices of items without affecting the total bid price [4,5]. In general, owners make the award decision based on the total bid price and do not pay much attention to variations in unit prices of items offered by different bidders. For this reason, it is more difficult to detect unbalanced bids created by quantity error exploitation for owners, especially in unit price contracts [3]. Therefore, this study focused on unbalanced bid created by quantity error exploitation in unit price contracts.

In the literature, there are numerous studies focusing on unbalanced bids in the construction industry. However, most of these studies have interested in developing optimization models to help contractors to win contracts and maximize profits of their bids, while offering the lowest potential bid price. On the other hand, limited models have been developed to help owners to detect and prevent unbalanced bids during the bid evaluation stage [4-7]. This study aims to provide owners with a model, which may assist them in detecting unbalanced bids. The proposed model uses five different grading systems. Owners may assign different weights to these grading systems and thereby the final score of each bidder can be calculated. All bidders can be evaluated based on the calculated final scores as well as the offered bid prices. In order to demonstrate how the proposed model can be performed in construction projects, an illustrative example is presented. The findings of this study revealed that the proposed model can help owners in detecting and preventing unbalanced bids during the bid evaluation stage.

2. The Concept of Unbalanced Bid

The idea of unbalanced bidding is not a new concept in the construction industry. Gates (1967) and Stark (1974) proposed effective studies on this phenomenon. Following these studies, numerous researches have been conducted to address unbalanced bids. Most of these studies represent a contractor's viewpoint on bid unbalancing. In many of them, models have been developed to help contractors in maximizing their profits while submitting the lowest possible bid price [8-11]. There are various disadvantages of unbalanced bids for owners. The most important ones are listed below [12-15]:

- Prevention of real competition environment,
- Risk of unbalanced bid being excluded in the bid evaluation stage, if it is detected by owner,
- Obligation of owner to pay in advance in unbalanced bid created by front-loading,
- Obligation of owner to pay more due to inflation in unbalanced bid created by end-loading,
- Failure of the lowest bid at the end of project,
- Ease of entry into the construction industry.

3. Detection and Prevention of Unbalanced Bids: The Developed Models

Owner efforts to detect unbalanced bids in advance as a preventive action because of its negative effects on the overall project performance. In the literature, there are limited studies that help owners in detecting and preventing unbalanced bids during the bid evaluation process. Unbalanced bids are not forbidden in the construction industry, but they are considered as unethical and risky strategy. If an owner has a mechanism to detect unbalanced bids, a fair competition environment can be created. Therefore, detection of unbalanced bids, especially quantity error exploitation, is a critical issue for owners. This type of unbalancing is much more difficult to detect than front-end loaded bids.

Bell (1989) proposed a single percentage factor method, which prevents unbalanced bidding in unit price contract. This method precludes quantity error exploitation bids and it also aims to prevent front-loading and end-loading of bid [16]. Wang (2004) developed an electronic based procedure to manage bid unbalancing in lump sum contracts. This method focuses on the adjustment of rates submitted by the lowest bidder in estimated quantities and the rates submitted by all qualified bidders without affecting the total bid price of bidder [17]. Arditi and Chotibhongs (2009) developed two separate processing models to detect front-end loaded and quantity error exploitation unbalanced bids. These models are based on comparing prices of each bid item with the engineer's estimates and the average prices offered by bidders [6]. Yin et al. (2010) stated that unbalanced bidding is a tool to win the contract with the lowest price for contractors. On the other hand, unbalanced bids may cause the low contract price but high project completion price. Therefore, their study provides the reference for owner's project investment control. Consequently, they recommend that unbalanced bid should be determined and eliminated by owner [14]. Renes (2012) suggested that unbalance bidding can be eliminated or mitigated by hiding quantities of activity estimated by owner. Renes (2012) also proposed that estimated quantities for each bid item may be presented to bidders as a range of values rather than as a single value [18]. Shrestha and Joshi (2012) conducted a linear correlation analysis to investigate whether bidders were applying front-end loading method [19]. Skitmore and Cattell (2013) presented a simulation study, which illustrates the likely impacts of using typical unbalanced bid detection methods under some assumptions [20]. Hyari (2015) proposed a model for prevention of unbalanced bids rather than detection. The model provides a systematic procedure, which uses the average unit price of all bidders to adjust unit price of every bid item submitted by each bidder without affecting the total bid amount of the bidder [4]. Hyari et al. (2016) presented a detection model to help owners in detecting unbalanced bids. The proposed model is based on considering uncertainty in estimated quantities of activity in order to detect unbalanced bids in the bid evaluation stage. The model uses Monte Carlo simulation to measure the risk impacts of differences between actual quantities of activity and estimated quantities to evaluate submitted bids [5].

4. The Proposed Unbalanced Bid Detection Model

This study aims to provide owners with a model, which may assist them in detecting unbalanced bids. For this purpose, the existing models were reviewed. The proposed model uses five different grading systems. Owners may assign different weights to these grading systems and thereby the final score of each bidder can be calculated. All bidders can be evaluated based on the calculated final scores as well as the offered bid prices. The five different grading systems in the proposed model are explained briefly in the below:

First grading system: The main idea behind this grading system is to compare the ratio of each activity's total price in the bid price offered by each bidder with the one estimated by the owner. From the bidder's viewpoint, the price of each activity i (i=1,2…n) is calculated multiplying its quantity (q_i) by its unit price estimated by the bidder (bup_i). From the owner's viewpoint, the price of each activity i (i=1,2…n) is calculated multiplying its quantity (q_i) by its unit price estimated by the owner (oup_i). The bid price (BP) is the sum of prices of every activity estimated by bidders (Eq. 1), whereas the estimated construction cost (ECC) is the sum of prices of every activity estimated by owner (Eq. 2). The ratio of each activity's total price estimated by each bidder in the bid price (br_i) and the ratio of each activity's total price estimated by the owner in the estimated construction cost (or_i) are calculated using Equations 3 and 4. Then the comparison ratio for the first grading system (r_1) is calculated by dividing br_i by or_i (see Eq. 5). Having calculated this comparison ratio, a grade is given to each activity (g_{1i}) based on the intervals given in Table 1. The total score obtained from the first grading system (BTS_1) is calculated using Eq. 6, where g_{max} is the maximum value of the grading system 1 (g_{max}=42).

$$BP = \sum_{i=1}^{n} bup_i \times q_i \tag{1}$$

$$ECC = \sum_{i=1}^{n} oup_i \times q_i \tag{2}$$

$$br_i = \frac{bup_i \times q_i}{BP} \tag{3}$$

$$or_i = \frac{oup_i \times q_i}{ECC} \tag{4}$$

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$$r_1 = \frac{br_i}{or_i} \tag{5}$$

$$BTS_1 = \frac{\sum_{i=1}^{n} br_i \times g_{1i}}{g_{\max}} \times 100 \tag{6}$$

Second grading system: The main idea behind this grading system is to compare the unit price of each activity *i* (bup_i) offered by each bidder with the ones estimated by the owner (oup_i). In this grading system, the comparison ratio (r_2) is calculated using Eq. 7. Bidders obtain a grade for each activity (g_{2i}) based on the intervals given in Table 1. The total score received from the second grading system (BTS_2) is found using Eq. 8, where g_{max} is the maximum value of the grading system 2 (g_{max}=42).

$$r_2 = \frac{bup_i}{oup_i} \tag{7}$$

$$BTS_2 = \frac{\sum_{i=1}^{n} br_i \times g_{2i}}{g_{\max}} \times 100 \tag{8}$$

Third grading system: The main idea behind this grading system is to compare the unit price of each activity (b_{upi}) offered by each bidder with the average of unit prices (aup_i) offered by *n* number of bidders. The average unit price of each activity is calculated using Eq. 9 and the comparison ratio (r_3) is calculated using Eq. 10. Bidders obtain the grade (g_{3i}) according to the comparison ratio obtained for each activity (see Table 1). Then, the total score received from the second grading system (BTS_3) is found using Eq. 11, where g_{max} is the maximum value of the grading system 3 (g_{max}=42).

$$aup_i = \frac{bup_1 + bup_{2+} ... + bup_n}{n} \tag{9}$$

$$r_3 = \frac{bup_i}{aup_i} \tag{10}$$

$$BTS_3 = \frac{\sum_{i=1}^{n} br_i \times g_{3i}}{g_{\max}} \times 100 \tag{11}$$

Fourth grading system: The main idea behind this grading system is to compare the bid price offered by the bidder (*BP*) with the estimated construction cost (*ECC*). The comparison ratio (r_4) is calculated by Eq. 12. Bidders obtain the grade (g_4) according to this ratio based on the intervals presented in Table 2. The total score for grading system 4 (BTS_4) is calculated using Eq. 13, where g_{max} = 21.

$$r_4 = \frac{BP}{ECC} \tag{12}$$

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$$BTS_4 = \frac{g_4}{g_{\max}} \times 100 \tag{13}$$

Fifth grading system: The main idea behind this grading system is to compare to the sum of total prices of activities whose quantities may likely increase during the construction phase offered by bidders (br_{is}) with the ones estimated by the owner (or_{is}) (see Equations 14-15). The comparison ratio (r_5) is calculated by Eq. 16. Bidders obtain the grade (g_5) according to the comparison ratio presented in Table 1. The total score for the grading system 5 (BTS_5) is calculated using Eq. 17, where $g_{max} = 42$.

$$br_{i_s} = \frac{bup_{i_s} \times q_{i_s}}{BP} \tag{14}$$

$$or_{i_s} = \frac{op_{i_s} \times q_{i_s}}{ECC} \tag{15}$$

$$r_5 = \frac{br_{i_s}}{or_{i_s}} \tag{16}$$

$$BTS_5 = \frac{g_5}{g_{\max}} \times 100 \tag{17}$$

Table 1. Grade values for grading system 1, 2, 3 and 5.

Comparison Ratio	Grade	Comparison Ratio	Grade	Comparison Ratio	Grade
$r \leq 0.9$	42	$0.965 < r \leq 0.970$	28	$1.035 < r \leq 1.040$	14
$0.900 < r \leq 0.905$	41	$0.970 < r \leq 0.975$	27	$1.040 < r \leq 1.045$	13
$0.905 < r \leq 0.910$	40	$0.975 < r \leq 0.980$	26	$1.045 < r \leq 1.050$	12
$0.910 < r \leq 0.915$	39	$0.980 < r \leq 0.985$	25	$1.050 < r \leq 1.055$	11
$0.915 < r \leq 0.920$	38	$0.985 < r \leq 0.990$	24	$1.055 < r \leq 1.060$	10
$0.920 < r \leq 0.925$	37	$0.990 < r \leq 0.995$	23	$1.060 < r \leq 1.065$	9
$0.925 < r \leq 0.930$	36	$0.995 < r \leq 1.000$	22	$1.065 < r \leq 1.070$	8
$0.930 < r \leq 0.935$	35	$1.000 < r \leq 1.005$	21	$1.070 < r \leq 1.075$	7
$0.935 < r \leq 0.940$	34	$1.005 < r \leq 1.010$	20	$1.075 < r \leq 1.080$	6
$0.940 < r \leq 0.945$	33	$1.010 < r \leq 1.015$	19	$1.080 < r \leq 1.085$	5
$0.945 < r \leq 0.950$	32	$1.015 < r \leq 1.020$	18	$1.085 < r \leq 1.090$	4
$0.950 < r \leq 0.955$	31	$1.020 < r \leq 1.025$	17	$1.090 < r \leq 1.095$	3
$0.955 < r \leq 0.960$	30	$1.025 < r \leq 1.030$	16	$1.095 < r \leq 1.100$	2
$0.960 < r \leq 0.965$	29	$1.030 < r \leq 1.035$	15	$1.100 < r$	1

Table 2. Grade values for grading system 4.

Comparison Ratio	Grade	Comparison Ratio	Grade
$r \leq 0.950$	21	$1.005 < r \leq 1.010$	10
$0.950 < r \leq 0.955$	20	$1.010 < r \leq 1.015$	9
$0.955 < r \leq 0.960$	19	$1.015 < r \leq 1.020$	8
$0.960 < r \leq 0.965$	18	$1.020 < r \leq 1.025$	7
$0.965 < r \leq 0.970$	17	$1.025 < r \leq 1.030$	6
$0.970 < r \leq 0.975$	16	$1.030 < r \leq 1.035$	5
$0.975 < r \leq 0.980$	15	$1.035 < r \leq 1.040$	4
$0.980 < r \leq 0.985$	14	$1.040 < r \leq 1.045$	3
$0.985 < r \leq 0.990$	13	$1.045 < r \leq 1.050$	2
$0.990 < r \leq 0.995$	12	$1.050 < r$	1
$0.995 < r \leq 1.000$	11		

A comparison rate is calculated for all grading systems. Bidders obtain grades according to these ratios. Grading tables (Tables 1 and 2) have been prepared so that bidders can be evaluated fairly. Two different grading tables were prepared within scope of the proposed model. Grading system 1, 2, 3, and 5 have a wide range, while grading system

4 has a narrow range. This indicates that grading system 4 is more sensitive than the others. In grading system 4, if the comparison rate is higher than 1.050, it gets the lowest grade *(g_{min}=1)*, while if it is lower than 0.950, it gives the highest grade (g_{max}=21). This function also applies to the others, only the limit values are different.

Finally, different weights to these grading system can be assigned to calculate the final score of each bidder. The final scores of bidders are calculated using Eq. 18 and they are evaluated based on their final scores as well as the total bid price.

$$FS = w_1 \times BTS_1 + w_2 \times BTS_2 + w_3 \times BTS_3 + w_4 \times BTS_4 + w_5 \times BTS_5 \tag{18}$$

where w_1 is the weight for the first grading system, w_2 is for the second one, w_3 is for the third one, w_4 is for the fourth one, w_5 is for the fifth one.

5. Illustrative Example

In order to illustrate how the proposed model can be applied in construction projects, an example is presented. The presented example consists of 72 activities, 10 of which are related to groundwork, in other words, quantities of these activities may increase during the construction phase. The unit price of each activity estimated by the owner are taken from "The Construction and Installation Unit Prices Book" published by Ministry of Environment and Urban Planning in Turkey. 8 different bidders have been asked to propose unit prices for these activities. The units, quantities, unit prices of these 72 activities estimated by the owner (O) and proposed by 8 bidders (B) are presented in Table 3.

Table 3. Input data for illustrative example.

Act. ID	**Unit**	**Quantity**	**Unit Prices (TL)**								
			O	**B_1**	**B_2**	**B_3**	**B_4**	**B_5**	**B_6**	**B_7**	**B_8**
A_1	m^3	700	14.38	14.75	13.07	15.50	15.56	14.92	13.64	14.88	14.66
A_2	m^3	365	38.83	41.91	41.25	42.38	35.58	41.11	38.14	40.41	36.32
A_3	m^3	850	2.84	3.08	2.59	2.96	2.63	2.98	2.84	2.86	2.68
A_4	m^3	736	4.83	5.29	4.57	5.27	5.15	4.36	4.46	4.62	4.72
A_5	m	198	67.70	65.94	63.94	74.14	65.43	69.76	68.75	69.39	62.33
A_6	m^3	59	31.88	29.82	28.96	29.66	29.41	33.12	29.21	28.89	29.34
A_7	m^3	150	14.19	13.60	13.21	14.34	13.67	13.78	15.17	13.64	15.11
A_8	m^3	90	29.19	26.97	28.68	29.95	31.42	30.40	31.12	29.52	30.38
A_9	m^3	2000	178.63	170.44	183.53	173.77	166.04	189.94	187.99	175.84	169.66
A_{10}	m	1200	335.43	330.84	362.48	336.29	333.25	322.75	318.94	329.43	353.08
A_{11}	m	650	68.40	65.53	74.79	69.38	63.26	64.79	69.13	72.10	73.25
A_{12}	m^3	350	52.20	51.26	47.00	54.89	56.72	47.53	54.14	52.51	56.04
A_{13}	m^3	100	86.29	84.53	92.11	85.72	91.16	88.14	85.52	88.90	82.79
A_{14}	m^3	360	121.63	112.82	133.19	131.99	130.73	122.52	128.27	111.87	124.88
A_{15}	m	36	29.19	29.64	28.97	30.16	27.98	28.77	31.89	29.44	27.92
A_{16}	m	40	33.40	35.59	34.05	32.36	36.04	35.12	36.57	32.56	36.23
A_{17}	m^2	1000	22.18	20.98	23.41	20.95	23.78	22.35	23.19	23.00	20.95
A_{18}	m^2	750	23.24	23.34	21.41	23.86	21.85	21.32	24.63	21.88	22.87
A_{19}	m^2	635	31.39	32.96	31.66	29.76	30.56	32.36	28.90	29.47	33.33
A_{20}	m^2	400	35.64	36.75	37.55	36.58	39.03	35.38	37.56	35.40	36.21
A_{21}	m^2	348	38.05	39.78	38.77	39.28	35.44	35.79	39.19	39.63	35.08
A_{22}	m^2	250	50.16	50.34	49.73	52.14	45.85	52.27	49.12	50.30	49.46
A_{23}	m^2	100	26.56	26.26	27.36	26.88	25.07	24.98	27.50	24.59	27.82
A_{24}	m^2	150	35.63	36.26	34.12	37.72	34.84	35.66	35.98	32.82	35.03
A_{25}	m^2	75	23.61	24.87	21.25	21.81	24.29	23.15	23.41	24.72	24.89
A_{26}	m^2	98	28.59	25.89	26.65	28.53	28.52	31.41	28.69	28.21	30.46
A_{27}	m^2	50	27.29	27.41	25.95	29.84	26.82	28.77	25.32	25.65	24.73
A_{28}	m^2	43	29.98	30.20	29.84	27.50	30.75	28.48	32.57	28.26	30.09
A_{29}	m^2	66	44.61	45.92	47.46	44.67	40.65	48.92	42.76	43.53	41.53
A_{30}	m^2	40	58.94	54.01	56.03	53.11	59.19	59.65	54.99	59.98	60.40
A_{31}	m^2	40	39.54	43.20	42.80	39.07	37.86	38.69	42.66	41.16	39.66
A_{32}	m^2	100	40.24	42.55	39.59	41.02	42.52	43.04	41.36	41.56	36.69
A_{33}	m^2	450	1.94	1.75	2.08	2.01	1.94	2.00	1.99	2.01	1.75
A_{34}	m^2	350	2.35	2.17	2.48	2.39	2.27	2.55	2.20	2.58	2.19
A_{35}	m^2	40	16.91	15.70	15.29	15.72	16.19	15.85	15.66	16.05	17.10
A_{36}	m^2	60	20.71	18.91	20.89	20.97	20.51	21.01	22.31	20.95	20.96
A_{37}	m^2	50	14.68	15.50	14.91	13.82	13.55	13.29	14.37	14.57	13.84

Table 3 (cont'd). Input data for illustrative example.

Act. ID	Unit	Quantity	Unit Prices (TL)								
			O	**B_1**	**B_2**	**B_3**	**B_4**	**B_5**	**B_6**	**B_7**	**B_8**
A_{38}	m^2	1000	27.71	26.86	27.56	26.32	29.55	26.55	26.78	27.64	28.43
A_{39}	m^2	450	43.24	39.04	46.78	45.19	46.00	43.59	45.01	45.12	47.13
A_{40}	m^2	900	32.39	34.31	29.90	34.25	33.58	32.77	29.28	31.71	29.34
A_{41}	m^2	650	33.90	33.90	30.71	36.87	36.48	30.83	35.46	31.94	31.03
A_{42}	m^2	100	6.29	6.84	5.71	6.33	5.92	5.68	5.97	6.86	6.02
A_{43}	m^2	1000	1.29	1.29	1.31	1.23	1.40	1.36	1.22	1.19	1.18
A_{44}	m^2	150	7.33	7.01	6.67	6.64	7.45	7.91	7.12	7.29	7.64
A_{45}	m^2	2000	11.78	11.58	12.45	11.39	11.86	12.38	11.66	12.90	12.94
A_{46}	m^2	1600	30.04	29.74	30.87	31.84	27.61	30.66	31.46	29.77	30.38
A_{47}	m^2	2000	29.56	30.55	30.33	30.01	32.43	28.17	30.23	29.49	27.07
A_{48}	m^3	600	4.59	4.65	4.72	4.72	4.68	4.50	4.27	4.87	4.15
A_{49}	m^3	450	5.84	5.36	6.42	5.29	5.88	6.11	5.41	6.06	5.64
A_{50}	m^2	750	4.83	5.29	4.61	4.97	5.18	4.77	4.79	4.86	5.21
A_{51}	m^2	1600	115.81	107.85	117.90	125.97	116.49	107.78	122.21	120.78	120.28
A_{52}	m^2	650	136.51	142.73	139.82	133.89	126.59	128.11	149.12	141.47	126.39
A_{53}	m^2	650	88.36	89.02	81.44	91.52	92.22	93.89	89.25	79.90	81.71
A_{54}	m^2	250	123.24	133.28	134.02	112.88	133.04	134.99	119.83	131.82	114.27
A_{55}	m^2	690	50.34	48.72	47.31	53.42	49.00	46.54	53.07	51.53	45.89
A_{56}	m^2	600	170.88	157.50	161.31	160.47	179.91	166.13	182.67	164.95	182.67
A_{57}	m^2	350	319.38	338.86	338.76	344.12	339.48	325.54	350.95	306.97	302.08
A_{58}	m^2	400	250.09	261.30	253.70	264.69	249.89	244.55	265.10	264.46	226.00
A_{59}	ton	1300	2096.56	2127.33	2152.31	1941.54	2089.57	2077.30	2026.49	1988.62	2045.57
A_{60}	ton	1650	2017.94	2140.37	2143.31	1877.71	1975.24	1998.95	1887.98	2160.53	1974.92
A_{61}	ton	350	1972.66	1871.37	1796.76	2120.92	2169.36	1789.12	2155.85	1837.37	1987.05
A_{62}	ton	1000	1939.23	1985.11	1832.36	1762.37	1999.50	2115.62	2044.00	1860.08	1918.36
A_{63}	ton	1150	1914.79	1914.13	1780.31	2038.14	1781.33	1987.31	1875.30	1810.11	1885.75
A_{64}	ton	200	3386.01	3642.50	3635.81	3425.98	3236.22	3658.23	3346.48	3591.23	3238.26
A_6	kg	4000	8.64	9.39	8.07	8.58	7.87	8.65	9.13	8.38	7.97
A_{66}	m^2	2000	9.59	9.16	10.29	10.06	9.74	10.16	9.55	8.82	10.51
A_{67}	m^2	600	13.00	12.96	13.32	14.30	14.00	13.68	11.84	12.36	14.07
A_{68}	m^2	150	5.23	5.62	5.34	5.53	5.32	5.06	4.91	5.17	5.45
A_{69}	m^2	2000	15.65	14.26	16.26	14.72	16.25	15.96	14.87	15.75	16.47
A_{70}	m^2	2000	18.56	19.20	16.81	18.13	19.78	18.95	17.37	17.73	18.78
A_{71}	m^2	700	28.60	27.78	27.36	26.28	31.23	30.24	27.97	27.13	28.49
A_{72}	m^2	2000	20.88	21.98	22.75	22.95	19.38	19.91	21.36	19.67	22.51

The estimated construction cost (*ECC*) estimated by the owner is 13,766,619.41 TL, and the bid prices offered by 8 bidders are 14,043,276.86 (BP_1), 13,826,569.14 (BP_2), 13,389,997.59 (BP_3), 13,624,850.19 (BP_4), 13,947,114.50 (BP_5), 13,622,893.85 (BP_6), 13,641,083.17 (BP_7), and 13,538,572.61 (BP_8), respectively. In this study, the weights are 20% for first grading system, 15% for the second one, 10% for the third one, 15% for the fourth one, and 40% for the fifth one. It should be kept in mind that these weights can differ depending on the needs of the owner. The final scores calculated for 8 bidders are presented in Table 4.

Table 4. Final scores of each bidder.

Bidders ID	Grad. Sys.#1 (20%)	Grad. Sys.#2 (15%)	Grad. Sys.#3 (10%)	Grad. Sys.#4 (15%)	Grad. Sys.#5 (40%)	Final Score	Ranking
B_1	61.71	52.74	39.12	31.82	50.00	48.94	6
B_2	58.84	56.31	45.27	50.00	66.67	58.91	2
B_3	57.99	68.34	59.75	77.27	2.38	40.37	8
B_4	59.25	64.84	53.22	63.64	54.76	58.35	3
B_5	61.14	54.01	42.19	40.91	42.86	47.83	7
B_6	58.83	64.07	53.38	63.64	52.38	57.21	4
B_7	57.67	62.71	52.26	59.09	38.10	50.27	5
B_8	60.07	67.24	57.40	68.18	61.90	62.83	1

Based on the final scores presented in Table 4, Bidder 8 (B_8) achieved the highest final score and Bidder 3 (B_3) achieved the lowest final score. Although B_3 offered the lowest bid price and received the highest grades from the second, third and fourth grading systems, it received the lowest final score because it received the lowest grade from the fifth grading system whose weight is the highest one. Consequently, B_3 achieved a very low score in the fifth grading system and this negatively affected the final score. On the other hand, B_8 is above average grade in all grading systems, although it does not offer the lowest bid price and has got the highest final score. Therefore, B_8 is the most appropriate bidder for the owner. It can be concluded that B_3 offers the most unbalanced bid, whereas B_8 offers the most balanced bid.

6. Conclusions

Unbalanced bidding is a major issue and an important unethical problem for owner in the construction industry. Owner has right to reject unbalanced bids, but it is hard to detect unbalancing because award decision depends on the total bid price and changes in unit price of bid items are usually not taken into consideration. For these reasons, it is more difficult to detect quantity error exploitation bids for owner, especially in unit price contracts. If an owner can detect an unbalanced bid, a fair competition environment can be created in the bidding process. This study focuses on quantity error exploitation bids in unit price contracts and aims to provide owners with a model, which assists them in detecting the potential unbalanced bids. In order to achieve this objective, the relevant literature was reviewed and then a model was proposed. The proposed model is designed to detect unbalanced bids by using five different grading systems. The final scores of bidders are calculated by assigning different weights to these grading systems. Bidders are evaluated according to their final scores as well as the total bid price. In order to demonstrate how the proposed model can be performed in construction projects, an illustrative example was presented. The outcomes of proposed model have shown that it is a useful tool for detecting unbalanced bids created by quantity error exploitation method in unit price contracts. This study also showed that when selecting the most appropriate contractor for project, owner should take into consideration not only bid price offered by bidders but also unit prices offered for each item. This study is limited as it only focuses on unbalanced bids created by quantity error exploitation method in unit price contracts. In future studies, the models addressing unbalanced bids in different types of contracts and created by front-end loading can be developed.

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Development of Verification System of Earthwork Amount using 3D Analysis Cell

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Abstract

The Efforts has been made with a fast speed to the automation of earthworks focused on global construction machinery enterprises. By using drone or terrestrial laser scanner, the work site can be measured rapidly and by using this it aims to provide various solutions to operate construction machinery effectively. In order to manage effectively the process of construction, it is important to figure out the changes of amount of earth cutting and banking with respective work site upon measuring the total volume of work in the progress of the project. In this study, the Analysis Cell introduced in earlier research is applied to the real work site to analyse the amount of work, cutting and banking. Applying to test bed, the amount of cutting and banking in the early stage were identified to have been decreased gradually in connection with the progress of works. Furthermore, based on Analysis Cell, it could be verified that work site has been changed to the similar shape of the design drawing.

Keywords: terrestrial laser scanner, analysis cell, earthwork amount, verification system ;

1. Introduction

The Effort has been made with fast pace to automate the earthwork construction focused on the global construction equipment enterprises such as Caterpillar and Komatsu. By using drone or TLS(terrestrial laser scanner), the work site can be measured rapidly and by using this, it aims to provide various solutions to operate construction machinery effectively. Such efforts by the global construction companies are expected to lead to an ultimate change in the work style of the construction industries. [1].

Currently, the equipment operating system is being developed to be focused on the efficient operation of the equipment by the global construction machinery enterprises; however, there is still an insufficient part to be applied to the construction work site. It is because the purpose of the construction industry is focusing on the effectiveness of process management, not on the efficient operation of equipment. In order to manage effectively the process of construction, it is important to figure out the changes of amount of earth cutting and banking with respective work site upon measuring the total volume of work in the progress of the project. The site manager establishes the work management schedule to perform effectively construction projects based on the management information.

D. Lee et al [2] proposed a methodology to manage the site using the Analysis Cell. In this study, the work site is split into 3D dimension and then the earth volume by respective Analysis Cell is examined. This study analyzes the amount of earthwork volume, cutting and banking, by applying the Analysis Cell to real work site.

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2. Creation of 3D Analysis Cell

It is necessary to establish the plan on how to operate the construction machinery of an excavator, a wheel loader, and a truck, etc. to perform earthwork efficiently. In order to do that, we should know the amount of earthwork and location information. D. Lee et al [2] presented the concept of three-dimensional Analysis Cell having the information to perform the earth work efficiently as illustrated in Fig.1.

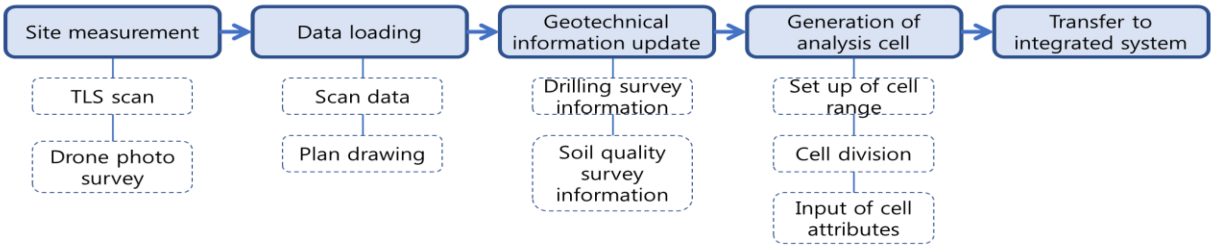


Fig. 1. Process of the 3D geotechnical analysis platform (referred from [1])

First, the site is scanned using the terrestrial laser scanner (TLS) and the site is measured using a drone. The site data (point cloud) measured by the TLS and the drone and the design drawing are imported. The drilling survey information and the soil quality survey information is updated in the imported data. At that point, the range of earthwork is established and the three-dimensional Analysis Cell is created. The Analysis Cell has the information on the amount of earthwork and the property of soil, etc. The changes in the amount of earthwork, cutting and banking. can be evaluated using the Analysis Cell according to the construction progress.

3. Case Study

The performance has been verified by applying the developed Analysis Cell system in the test bed of earthwork. The experiment was realized in December, 2017, the analysis was implemented by targeting the earthwork over a 4 days period. The experiment location was in empty ground located in Ansan City, Gyeonggi-do, Republic of Korea. Fig.2 is the aerial view of the work site that the experiment was being realized. The cutting and banking are signified at point A, and point B signifies the spoil area.

Fig. 2. The aerial view of work site

Based on the data scanned from real work site and the design drawing, the initial Analysis Cell has been created as shown in Fig.3. The Analysis Cell includes the information of amount of earthwork, cutting and banking, evaluated by comparing the design drawing and the real work site. The amount of cutting and banking can be calculated for the construction work site based on the information of each Analysis Cell. The construction manager is able to establish the operation plan for the construction machinery based on the analyzed total amount of earthwork.

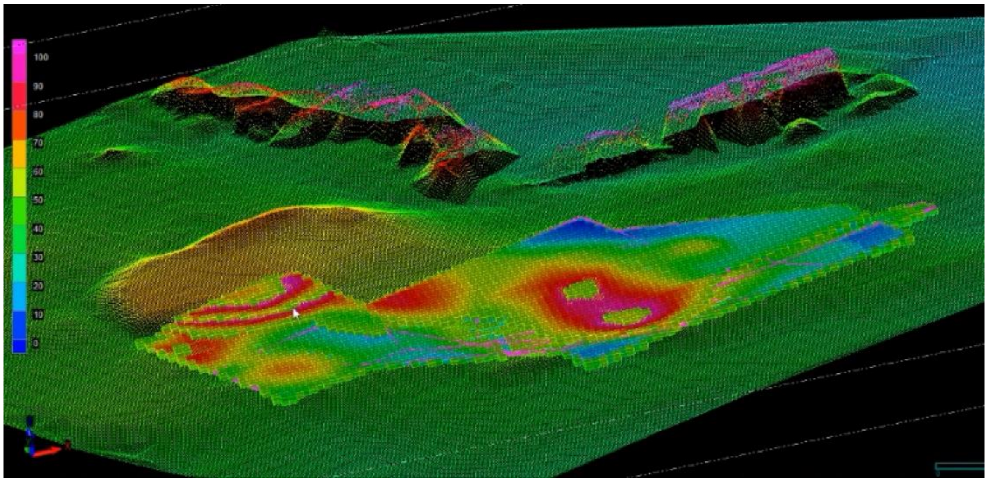
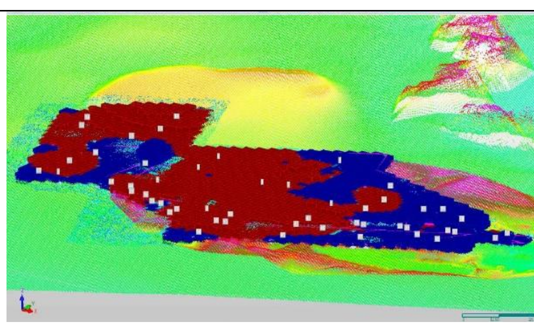


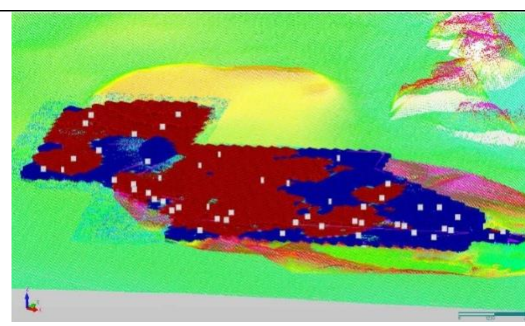
Fig. 3. The early creation of stage of Analysis Cell

Changes occur in the topography of work site through the earthwork over four days. The work progressed, so that it may be the same type as the design drawing, and sand was transported from the location that cutting was necessary to the location that banking was necessary. The earthwork was performed by utilizing two excavators, one truck, and one dozer in the test bed. The cutting and banking work performed focused on the area A in the 1st and the 2nd day. The work in the spoiled area at point B area occurred on the 3rd and 4th day.

Fig. 4 shows the changes in the amount of work by the number of work days. The red colored territory in the figure is the point where cutting or banking is necessary in relation to the real topography compared with the design drawing. The blue colored territory is the point where there is no significant difference between the design drawing. The blue colored Analysis Cell similar to the territory with the design drawing can be identified as the total work which progressed from the 1st day to the 4th day. On the contrary, the red colored territory decreases gradually.



(a) 1st day



(b) 2nd day

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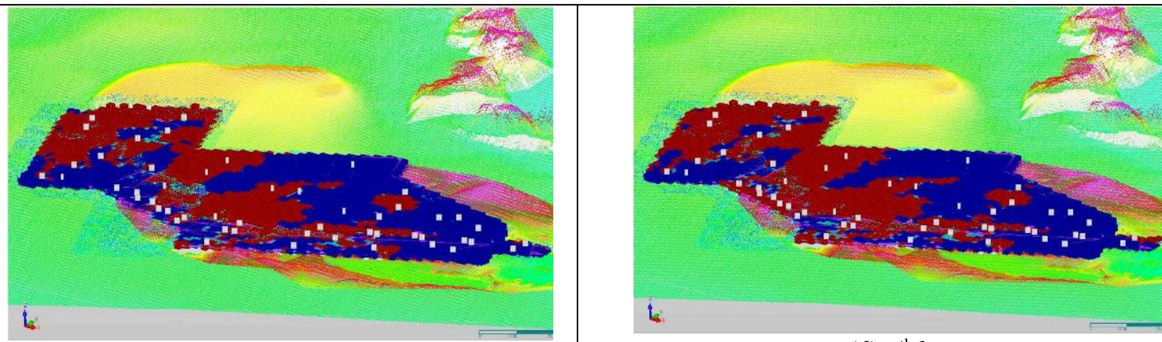
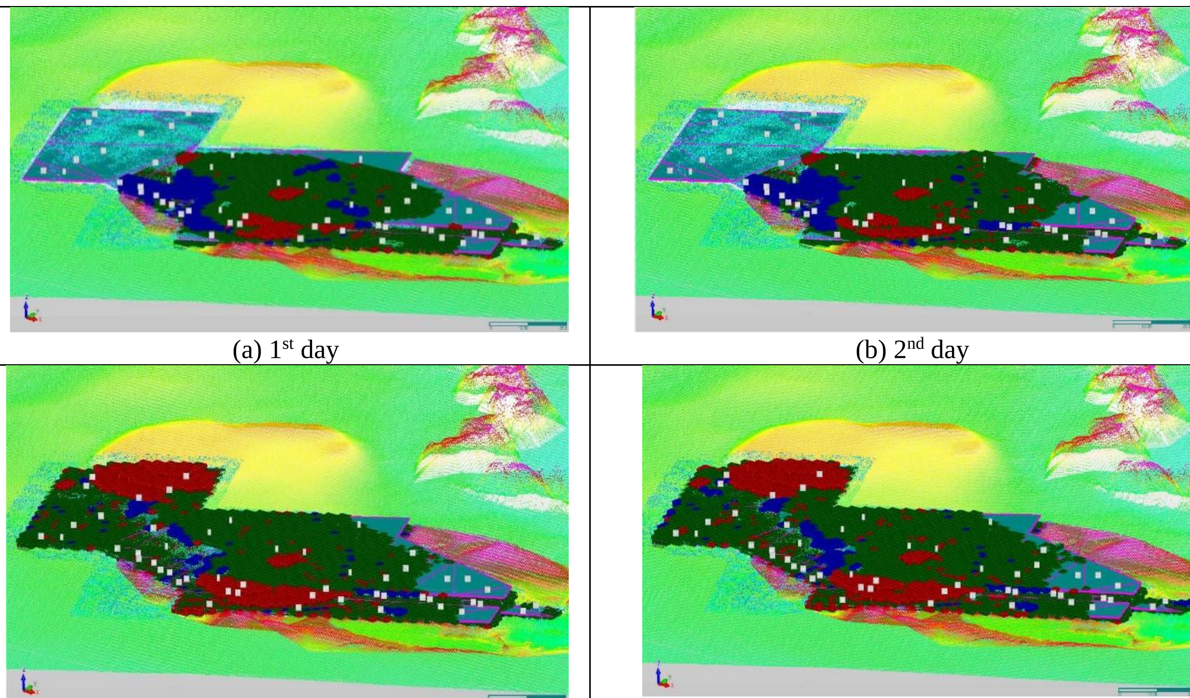


(c) 3rd day (d) 4th day

Fig. 4. The change for the amount of work

Fig.5 shows the changes in the amount of cutting and banking. The blue colored territory is the region where the banking is necessary, and the red colored territory is the region where cutting is necessary. The blue colored territory located on the left side decreased as the work progressed; the red colored territory that occurred at point of B was used as the temporary spoil area.



(a) 1st day (b) 2nd day

(c) 3rd day (d) 4th day

Fig. 5. The change of the amount of cutting and banking

Table 1 is the change of Analysis Cell arranged for the 4-day period. 4,263 units of Analysis Cell were created based on the plan drawing and the scanned data of site in the initial stage, the total amount of cutting was analyzed as 3,177m^3, and the total amount of banking was analyzed as 2,806m^3. From that point, Analysis Cell with the cutting and the adding Analysis Cell with the banking disappeared as the earthwork progressed. Besides, the amount of cutting and banking that each cell has changed as the work progressed. was noted that the number of Analysis Cell were being decreased, and the amount of cutting and banking is being decreased as the work is progressed by 4th day.

Table 1. Analysis result

Number	*The number*	*Added cell*	*Deleted cell*	*Changed cell*	The amount	The amount

scanned times	*of Analysis Cell*				of cutting *(m³)*	of banking *(m³)*
initial stage	4263	0	0	0	3177.204	2806.481
1st day	4324	296	235	1955	3005.100	2293.701
2nd day	4202	283	344	2026	2777.980	2019.693
3rd day	3707	277	833	2786	726.878	2659.062
4th day	3654	267	376	2758	810.688	2324.605

4. Conclusion

The methodology for analyzing the change in the amount of earthwork has been presented by comparing the design drawing and the measured topography by this research. It has been shown that the change in the amount of earthwork by each location may be seen visually through the application of creating the three-dimensional Analysis Cell. The result of test bed application shows changes of amount of earthwork at work site. The result presents that the amount of cutting and banking identified in the initial stage is decreased gradually as the work progressed. Also, this paper shows that the work sites are changed into the site planned in the design drawing using the Analysis Cell. In this research, the developed system was applied during earthwork period, not for whole earthwork periods.

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Effective Process of Project Monitoring and Control

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Abstract

Cost overrun, potential risks and delay are very common in construction projects due to many factors caused by project participants mainly during construction phase. Effective project monitoring and control is considered one of main factors that contractor's project managers must adopt to track and assess the progress of any construction project. The objective of the research is to determine why project monitoring and control is important for project progress, and what are the best practical techniques that can be used to monitor and track the work progress for any project, and to identify and make timely recommendations for necessary corrective action in response to any schedule delays. Monitoring and control is directly linked to the project management and construction management process to evaluate the project performance that will help the project manager to determine and decide if the project will be completed and delivered on time without any delay. Monitoring is concerned primarily with the ongoing collection of information's and reviews them on regular basis.

The results of the study revealed the necessity of needs that must be focused on internal control process and techniques e.g. contractor selection, construction phase, internal control process, job costing and labor management, part of the results are developing the necessary smart effective project controls before starting the execution stage. In the conclusion, good internal controls are vital for contractor's project managers through proper effective utilization and adoption to monitoring and control process of construction process including the available techniques that must provide and improve the efficiency of tracking tools.

Keywords: *Contractor Project Manager, Control process, Monitoring process, Planning, Risk control.*

1. Introduction:

Construction project works in a changing and dynamic environment, therefore it is extremely important to monitor and control the project work phases regularly and adopt suitable controlling methodologies and measures to keep it as planned. So the system should be in the place to avoid any delays. Many construction firms use time, cost and quality as a parameters to measure and control the projects. The purpose of control system is to ensure that project objectives within cost and quality are achieved within the approved/agreed time. Many other parameters must be considered to in addition to the traditional once time, cost and quality such as variations, delivery of materials, risk identification, availability of resource, numbers of claims and numbers of accidents. Senior management refer always to the approved working program once they get the feedback from the project managers through monitoring and control process, in case of any deviation of the work progress a corrective action should be taken to cover the impacted delay. The purpose of monitoring system is to check the continuity of work progress against the plan to help in taking any corrective action. Basic objectives of monitoring are to monitor projects by measuring physical progress according to [1].

Keeping the project with respect to schedule, budget and performance specifications requires special attention and focus by the project team mainly project manager through proper specific parameters like changes, communication, follow-up, meetings, inspections, performance, earned value and number of changes. More complex monitoring

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involves collecting data from individual participation of the team or through developed forms as stated by [2.] Monitoring is concerned with the ingoing review of information on the project execution, by collecting information regularly through project phases a project monitoring system can be developed to evaluate the quality of project objectives.

2. Literature review:

One of the major components of any construction/contracting firms in construction industry is the project especially huge and mega projects that creates big completion in the work environment to stake holders and other project execution team who become involved in work progress and daily operations by focusing on the activities and tasks that requires special monitor and control. This leads the organization/ firm to seek the excellence in accomplishing the task as confirmed by [3]. The successful project execution always start with proper planning for the activities that must be completed including the process of execution for these activities. This has to be monitored by the project managers through specific tools. Tools availability is critical factors in the productivity of construction team as stated by [4]. Most of construction projects are not performing to the level of expectations of the stakeholder and the project team due to many factors where some of these factors are lack of monitoring. Almost no construction project performs totally as planned as dynamic changes are frequently needed, these changes can be ascribed to the high uncertainty based on statement of [5].

Projects managers of contracting sectors required to have a certain level of skills to monitor and control projects at various stages of projects life cycles. Controls serve a particular purpose for each project phase. Professional quantity surveyors can use construction auditing skills at various stages of project life cycle to reduce the cost as stated by [6]. Project managers should have integrated system to control and monitor the project that must be agreed and approved during the planning phase of the project. The tools of monitoring could be automated or physical depending on the type and the size of the project and the capability of the contractors firms. Automated and integrated project monitoring and control frame work that facilitate decision making by project managers to take corrective actions after deviation occur referring to [7].

Many common methods are being in use for monitoring and controlling projects that leads to maximum achievement of objectives. Some of these methods have been investigated to find out the effectiveness of some commonly used monitoring system, in detecting deviations from the planned cost and performance as confirmed by [8]. Many factors are attributing to poor monitoring and control in construction projects like method of evaluating and reporting actual work vs planned, lack of information of material management and the inaccurate reported information that leads to a major delay in the project. Current, manuals, materials management and poor control procedures are some factors attribute to lack of up-to-date, real- time information as stated by [9]. Monitoring and control is related directly to project management and it is essential to assess and improve the project performance. It helps project managers to evaluate the status of the project whether the objectives are being met. Monitoring can identify the operational constraints that affect the performance of the project.

3. Overview of projects controls:

Potential applications **of** knowledge and information based expert system in the field of construction project monitoring and control are essential where these applications should be developed and updated at the end of each project according to the reported learned lessons of project managers. Applications and systems could be physical or software's programs performed by highly skilled people as long as it serves the achievement of project objectives. The applications are useful to identify and make timely recommendations for corrective action in response to the anticipated schedule delay. Implementing of the reported information in flexible process modeling approach like process configuration method enhance an alternative process planning where software system can be developed to minimize manual inputs and enhance data acquisition as recorded by [10]. Benefits of software are to make project managers and planners anticipate and identify schedule delays and expectation early before they happen. Analysis of the data collected and quality diverted items can be transformed into categorized factors. New technology mainly

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sensor technology provides the increased opportunities for automation and improvement the acquisition and construction process referring to [11].

The practical process of planning in construction project is still conflicted with provided information about of current process and necessary changes in the process flow must be adjusted during project execution. In practice, project managers and planners still depend on manual process methods to collect information during project execution. Accordingly, the information of actual construction process will become incomplete. It is extremely important to consider and establish an effective project planning, monitoring and control system to enhance project performance in order to minimize or avoid potential delays. Projects managers and planners must be aware that productivity of the human resources in construction can also be monitored and controlled but still productivity still can be improved. A framework for semi-automated project monitoring and control has been proposed where the collected data can be incorporated taking into account the impact of productivity of existing deviations from the planned performance and the controlling actions proposed to deal with these deviations based on what has been stated by [12].

Monitoring and controlling process in construction projects oversees all necessary tasks and metrics to ensure that the work progress of the project is within the scope, time and the budget so that potential risks can be mitigated. A part of the process is the comparison between the planned and actual for taking the corrective action to complete and handover the project on time especially if any deviations are occurred. Project control are the data gathering and analytical process used by the project team through the communication of information transmitted by a designed templates that complies with the nature of the project to assist the project leaders in decision making. Controlling the work can also be expressed as those measures that are necessary to make sure the expected happens. The project control with respect to the schedule, cost and quality is very important to project success that must be supported by the entire project staff referring to [13]. Project control can be achieved by developing a policy of understanding cost, time and quality through spreading their importance.

4. Current processes of Project Monitoring and Control:

Assessment, evaluation and comparison of actual results against the planned are essential in construction projects to ensure that the project activities are in progress. If there is a variance a corrective action by the project manager must be taken to keep the project within the time and the cost to prevent any delay. This can be achieved by checking regularly the project plan and weekly/monthly report that covers the collected data from other project team mainly the planners. A part of projects manager's responsibilities is to identify the reasons of problems that caused the deviations and to take corrective action. Reporting method that is a part of communication process must be approved at the beginning of the project by all stakeholders. If reporting method/plan is not sufficient, project can't be monitored and controlled properly. Control process and framework is different from a project to another depending on the size and type of project where different levels of management are involved. Project data and information must be always available on time. In construction projects actual data from construction site is not always available in real time, thus counter measures to offset unforeseen events are not triggered until it is fairly late, leading to costly delay in progress as recorded by [14].

There must be an approved control system for collecting the data where if the system is complex many potential issues will results that increases the cost and errors in working process. The accuracy of the data collection process can be influenced and maintained by accomplishment of certain practical actions through committed project team. Project team are always addressing the how the execution of activities will be monitored and how progress will be reported. Maintaining up-to-date time sheet and records of activities they are involved has to be reported regularly to the project manager to identify any potential issues that may cause a delay to project. The quality of the data and information should be performed to the highest level of efficiency. Many projects are getting delayed because of the lack of accuracy of the reported progress that are not matching with the actual work where project managers action is not reflecting the real action. Therefore the project team members must develop certain actual attitude towards the value of the data at early stage of the project. The collected information and the data must be readable, measurable and objective; monitoring the work progress of the tasks in construction projects should not be judged or evaluated in percentage wise.

Most of project managers are focusing on some points during monitoring and controlling to obtain regular progress and status reports, these points are Tracking, reviewing and regulating project progress, Progress measurement, forecasting, reports on scope, schedule, cost resources, quality and risks, Project document changes, Formalizing acceptance of deliverable during handing over, Records of quality control results and Implementing risk management plans. This requires a pro-active approach and full commitment by the project team and project manager. It is important to realize that scheduling requires a pro-active approach to ensure all relevant inputs are captured and there is a good understanding of the execution assumption and schedule risk referring to what confirmed by [15].

5. Aims and Objectives of Study:

This paper is mainly focused on the best practices and implementations of project monitoring and control that must be adopted by the project manager and his team. Construction project is considered to as of the achievement of a specific objectives that involves a series of activities and tasks that consume resources and time; the project manager should be ready to monitor the activities through a certain approved plan with the project team. The impact of failing of adopting the best practices of monitoring and control processes will be assessed and analyzed in this study where recommended actions has been demonstrated to show the necessities of adopting the process.

6. Methodology

To achieve the study objectives of this paper, a mixture of comprehensive methods were adopted in this study including literature review, questionnaire, and quantitative and qualitative data analysis. The theoretical background, literature review and overall objectives of the study have been reviewed, where overall processes of the study and adopted methods of analysis has been demonstrated. This part aims to describe the various methods that are available to the author during the study

6.1 Research Approach

The study method is prepared based on the analysis of the two main approaches of data collection: quantitative and qualitative analysis, both are identified below in order to allow the author a satisfactory understanding of how these methods are utilized in order to develop a detailed methodology of analysis.

6.2 Quantitative analysis

In short, quantitative analysis is the examination of data collected via survey techniques through statistical methods in order to ensure that the data collected is both reliable and significant.

6.3 Qualitative Analysis

The qualitative approach to research as the study of things in their natural setting, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them as confirmed by [16].

6.4 Data Collection

There are two main types of data that can be collected by researchers in order to develop the results that they require. These are primary and secondary data, and each will be dealt with in turn in order to describe how each type of data will be collected.

6.5 Primary Data Collection

Primary data are generated by the author who designed questionnaires and collected the data and did the required analysis. The author has described why and how the data were collected and explained about the method used for analyzing the data. Primary data has been collected from various sources; the author is responsible for the interpretation of the data. The primary data collection approaches are observation, experimentation, questionnaire and interviews.

6.6 Questionnaire

Questionnaire surveys are one of the methods to gather the information's /data where project managers are requested to fill the forms of questions. It includes list of questions related to the study topic. Questions mainly are selection base. This form of data collection is the most widely used source of primary research amongst researcher as it provided access to a wide range of professionals which would normally be beyond the reach of most researchers based on[17].

7.0 Design of questionnaire survey and data analysis:

Questionnaires are developed to collect the required information's to identify level of implications of processes that adopted by project managers and his team to monitor and control progress of the work at very effective method. Table I. shows the eight important points that should be followed by the project managers to monitor the work. The questionnaire survey is designed to evaluate and review the perceptions of project managers to the applications of internal control skills on construction projects. The survey was designed based on important eight processes that have been investigated in the literature review of the study. Participants have been requested to point out the level of significance and meaning of each process. The points are:-

- Establishing baseline that must be developed representing expecting performance
- Monitoring status in terms of performance that must be measured regularly against baselines
- Forecasts that present projections that will be made predicting future performance
- Variances through predicted performance variances that must be quantified
- Analysis based the analysis of the potential effects of variances on final cost and schedule
- Alternative options through corrective actions that must be evaluated and compared
- Implementation of corrective action that should be implemented by modifying work plan
- Assessment of remedy based on the associated work with the corrective action that must be monitored to assure its success.

Table 1. Several Important actions to be considered by project manager and his team

SN	Question/process	Validity	Means	Rendering	Standard deviation
1	Establishing baseline that must be developed representing expecting performance	100	2.94	56%	1.530
2	Monitoring status in terms of performance that must be measured regularly against baselines	100	2.95	56%	1.542
3	Forecasts that present projections that will be made predicting future performance	100	3.84	63%	2.733
4	Variances through predicted performance variances that must be quantified	100	3.89	66%	2.859
5	Analysis based the analysis of the potential effects of variances on final cost and schedule	100	2.30	51%	1.432
6	Alternative options through corrective actions that must be evaluated and compared	100	4.89	73%	2.896
7	Implementation of corrective action that should be implemented by modifying work plan	100	3.87	67%	1.677
8	Assessment of remedy based on the associated work with the corrective action that must be monitored to assure its success.	100	3.41	60%	1.595

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8.0 Data analysis and findings:

One hundred questionnaires were distributed to 100 contractor's project managers and schedulers working in five different contracting companies specialized in construction projects. Ten questionnaires were filled by project managers and the other ten was filled by schedulers in each company. Participants were very interested in the topic and the types of implications of project monitoring and control mainly Processes and actions listed in Table 1. they all confirmed that they are willing to respond to this study because the listed items is a part of their daily tasks in projects but not the expected level due to other daily tasks they are handling, most of them have confirmed that they depend on the recommendations reported by the scheduler on weekly basis because many of them are busy in solving contractual issue, meetings and follow up with sub-contractors. This part of the study is to find out the act upon the responses analysis that rendered through the questionnaire.

The analysis is prepared based on analyzed regression founded on the estimated relationship among the variables and the calculated frequencies, standard deviations, means for providing the responded participants view to a particular question. The purpose of the collecting and analyzing the data is to find out the level of the commitment of project managers and their schedulers of implicating monitoring and control process and to find out the impact of ignoring these implications and the best practices required to ensure that project is monitored and controlled to the maximum level as recommended at the end of that study. Establishing based line factor, it is observed that the value of standard deviation is 1.530, means that the variables are notably increase across the mean 2.94. As rendered based on Table I that 56 % do care about developing the baseline schedule that covers all activities. Monitoring the status against the baseline of each phase of project that is a part of responsibilities of the project team as listed in Table I, value of standard deviation of 1.542 shows that the results are greatly spread across the mean value of 2.95, suggests that around 56 % of the respondents confirmed that project team are monitoring but not to the extent required level due to other activities.

Factor of forecasting projection of evaluating the performance, the standard value deviation of this factor is 2.733, shows the results spreading across the mean value of 3.84 as shown in Table I where 63 % of the respondents stated that forecasting projection of the project is always investigated and checked by the project team. For the item of quantifications of variance the results are spread across mean of 3.89 as shown in Table I and standard deviation is 2.859 where 66 % of respondents reported that variances are considered by schedulers through the available software's like primavera. They also believe that it is the responsibilities of the project manager who deals directly with finance and budget department. They are not involved in financial issues because they focus to complete the task and leave financial issues to project manager.

The mean of the activity of analyzing of potential effects of variance is 2.30 and the standard deviation is 1.432 which indicates that 51% of the participants are doing approximate analysis for the effects and impacts on the variance. Scheduler and project manager are taking care of that activity on monthly basis based on generated reports of available software's in the project. 73% of respondents confirmed that considering alternative option through corrective action is one of the essential tasks that considered and discussed by the projects managers and his team based on the risk analysis at the beginning of the project. the standard deviation of this activity is 2.896 where its mean is 4.89. The implementation of corrective actions its standard deviation is 1.677 because 67% of the respondents stated that it is very important activity that must be monitored and controlled to mitigate any issues based on the order of project managers. This activity is controlled to maintain quality, time and cost of the project. 60 % of respondents stated that activity of assessment of remedy based of the associated work with the corrective action that its standard deviation is 1.595 and its mean is 3.41 must be regularly monitored to assure its success. Specific team will be assigned temporarily to ensure that work will be implemented on the agreed specific time.

Conclusion:

Due to fast growth of construction industry projects and fast development of real-estate projects at global level made project monitoring and control procedure very essential for project manager's, planners and schedulers. Project team must be familiar with project management knowledge and applications including the standards and methods that must be adopted and applied on day-to-day activities. These coupled with the critically of completing projects according to the agreed scope, time and cost as stated by [18]. Senior management of construction organizations must make sure that all of their projects managers are adopting the necessary best practices of project monitoring and control that help to keep the project on track during each phase. Monitoring and control activities keep checking if any deviation accrues during the work progress. Some of the important activities are taking action to control the project through necessary steps and control points that must be monitored to provide if the project is deviating from the baseline. Measuring the cost performance to check if the planned budget is sufficient to deliver the project and measuring the schedule performance to ensure that the planned schedule and dates can be achieved. Preparing in advance the necessary actions for variances exceeds the planned duration by 15-25% percentage. Taking a preventive action to mitigate factors affecting the causes of changes. In case of deviation from planned values, project managers must raise a change request to meet the planned values; in addition, changes must be implemented in performed integrated manner to come out with a proper evaluation for the changes impacts to reduce risks of changes. Checking the quality plans of the activities to ensure that of quality assurance and control are implemented for activities and final project components. Documenting all anticipated risks after categorizing and analyzing them, risk response strategies for each risk must be planned where action must be monitored and followed till the risk is closed. The proper administration of the necessary equipments, tools and sub-contracting resources must be properly monitored by purchasing managers who should communicate regularly with the project manager through regular weekly reports.

9.0 Recommendation:

On large scales of construction projects, monitoring and control process must be practiced to the highest level by the project team and project manager. During the work progress, project reports and data must be analyzed regularly at different phases of project. Analysis and assessment of much information including variances should be directed in successively at greater level of details to find out precisely the problems in the project and how they affect the schedule. The project manager has to determine who has responsibility for dealing with the problem and time should be fixed to recover it based on the decided corrective action. Evaluation and comparison of actual measured results against planned is the fundamental of project monitoring and control where corrective action is required if there is a variances to keep the project on schedule all the times. Progress report should be very accurate because it contains data collected from the site based on actual progress where the project manager has to collect measure and assess and re-plan (if necessary).

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Enhancing Lean Concept in precast concrete manufacturing with advanced Material Requirements Planning System

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Abstract

Companies operating in the construction industry, like many other companies in the manufacturing industries, in order to maintain their position on the global market, optimize inventories and the production processes. The need to minimize costs and maximize profits from manufacturing, while maintaining a high quality of products means that the "Lean manufacturing" concept must be implemented in all departments of the precast concrete production company. Delivery of prefabricated elements to construction sites is currently carried out based on detailed delivery schedules. These conditions mean that the "Just in time manufacturing" methodology is implemented in the precast concrete production companies. The high costs associated with the need to maintain stocks and resulting from the cost of creating the inventory and cost of maintaining the inventory are certainly not without significance. Achieving these goals is not possible only through detailed production planning, accurate cost determination, better use of storage and manufacturing infrastructure and forecasting sales volumes. In this case, considering the current reduction of inventories, accurate determination of delivery times of raw materials and semi-finished products is also important. The purpose of this paper is to present the method of planning material requirements for precast concrete manufacturing plants based on the MRP (Material Requirement Planning) system.

Keywords: construction industry, lean concept, material requirements planning, precast production

1. Introduction

Low productivity, inefficient use of machine and labor resources as well as excessive stocks are not new concerns in the construction industry. Already in the 1970s, the issues of productivity in the construction industry have been widely studied [7]. In the 1980s the research on improving production efficiency was continued [5] among others the impact of labor on production efficiency was analyzed [18], productivity in the construction sector was measured [19] and the field of Productivity Engineering and Management was intensively developed [8]. This decade is also the further implementation of the Japanese "Just-in-Time" concept, started by the Toyota Motor Corporation in the early 1950s [21] that is a management philosophy which enables to integrate and streamline the manufacturing system into its simplest possible processes [11]. The effective implementation of JIT has the benefits of reduced inventory levels, improved employee levels, improved employee morale, improved performance and profitability [10]. The effective implementation of JIT results in benefits in terms of reduced inventory levels, improved employee improvement, and improvement in productivity and profitability [11]. Over the following years, there was also an intense progress in the field of computer techniques, which contributed to the development of many models

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supporting the production processes of precast concrete products, such as the Artificial Intelligence Planner (AIP) [17]. AIP is capable of two functionalities. The first is a data integration system that encourages the automation in the planning process [17]. Current research trends in the field of precast production focus on optimization with the use of genetic algorithms of total production costs while meeting internal resource constraints and the construction site demands for precast elements [16]. Additionally, when developing optimization models, distribution costs, holding and backorder are minimized. For this purpose, among others, genetic algorithms (GAs) for optimizing novel mathematical models, Just-in-Time logistics and each-cycle lengths (JIT-L) were used [15].

Practice shows that in industrial plants producing large-scale pre-cast concrete units, it is necessary to implement integrated systems supporting the quick decision-making process in the field of order planning. However, there are many small production plants on the construction market, for which the costs of implementing such systems are too high. In addition, the number of components necessary for assembly in the production of precast concrete products is much smaller than, for example, in the automotive industry, thus making entire processes less complicated. Considering the above, there is a need to develop transparent systems adapted to support orders for products with a structure consisting of a small number of levels.

2. Material Requirements Planning System

The MRP system (Material Requirements Planning) is a supporting tool managing inventory and enabling the creation of plans for the supply of materials and raw materials necessary for production demands [13], [3].

The main objective of the system is to ensure an adequate amount of raw materials and materials necessary to carry out the planned production and supply to the customer, maintain the lowest possible level of inventory and support the planning policy of the enterprise related to the creation of delivery schedules and assembly operations. The basis for the MRP's functioning is to determine the material needs in the assumed time periods, which are the translation of the overarching production plan for orders of elements and subassemblies that are part of the structure of a given product.

The material requirements planning system is based on the following three sets of information:

- main production schedule,
- product structure collection,
- the main set of stocks.

The association of the listed sets with the MRP system is presented in Figure 1.

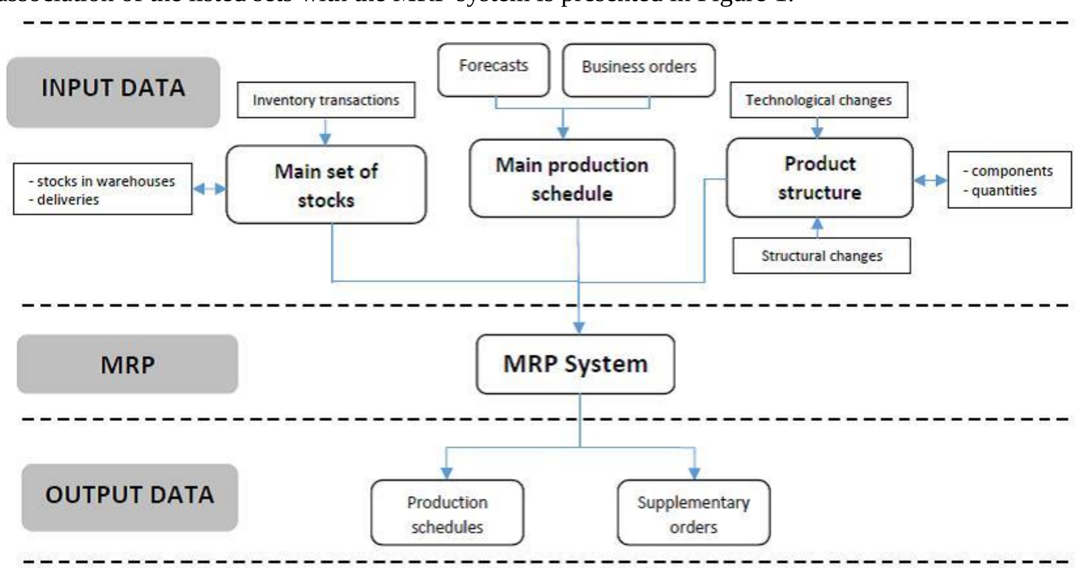

Fig. 1. MRP system information sets and streams – on the basis of [4].

The basic data are the duration of certain processes, in particular periods of execution of the desired parts (subassemblies, assemblies) by a "lower" (delivery) production site, or execution of orders directed to external suppliers [4].

A key aspect when planning material requirements is knowledge of the main production schedule, the main set of stocks and product structure. The process of choosing the suitable date of the order must be followed by back-planning, taking into account the moment of placing the order, delivery time to the warehouse and preparation for assembly. In addition, an ongoing monitoring of the level of stocks in warehouses and deliveries needs to be carried out. The structure of the manufactured products and in particular its complexity, expressed in the number of levels and elements forming the structure, also has an impact.

3. Adopting MRP into precast concrete plants

The implementation of the MRP system for precast concrete plants requires analyzing the specificity of the construction industry and construction products in terms of technology and organization. Not without significance are also aspects of risks occurring in precast concrete manufacturing [1]. Precast production plants are generally not automated to a large extent as production plants from other industries, such as, for example, electrical engineering, automotive, and pharmaceutical. There is still a large interest in concrete prefabrication on the market [10] and precast fabrication still strongly depends on labor [6]. In addition, orders are implemented primarily for construction companies, which are carrying out construction contracts based on detailed construction schedules, mostly including high contractual penalties for any delay [9]. Thus, it is necessary to produce an element for a specific project and within a strictly defined period. Therefore, orders should be made according to the Just-in-Time methodology. Another factor influencing the development of the MRP system is the seasonality of construction in many countries and the resulting variability in orders over the year. The winter period is usually associated with a reduction of construction works, which directly affects the production assumptions, and, above all, the strategy of resource procurement. Skipping this in combination with inaccurate planning methods, inefficient resource utilization often affect overstocking in the precast industry [20], [14].

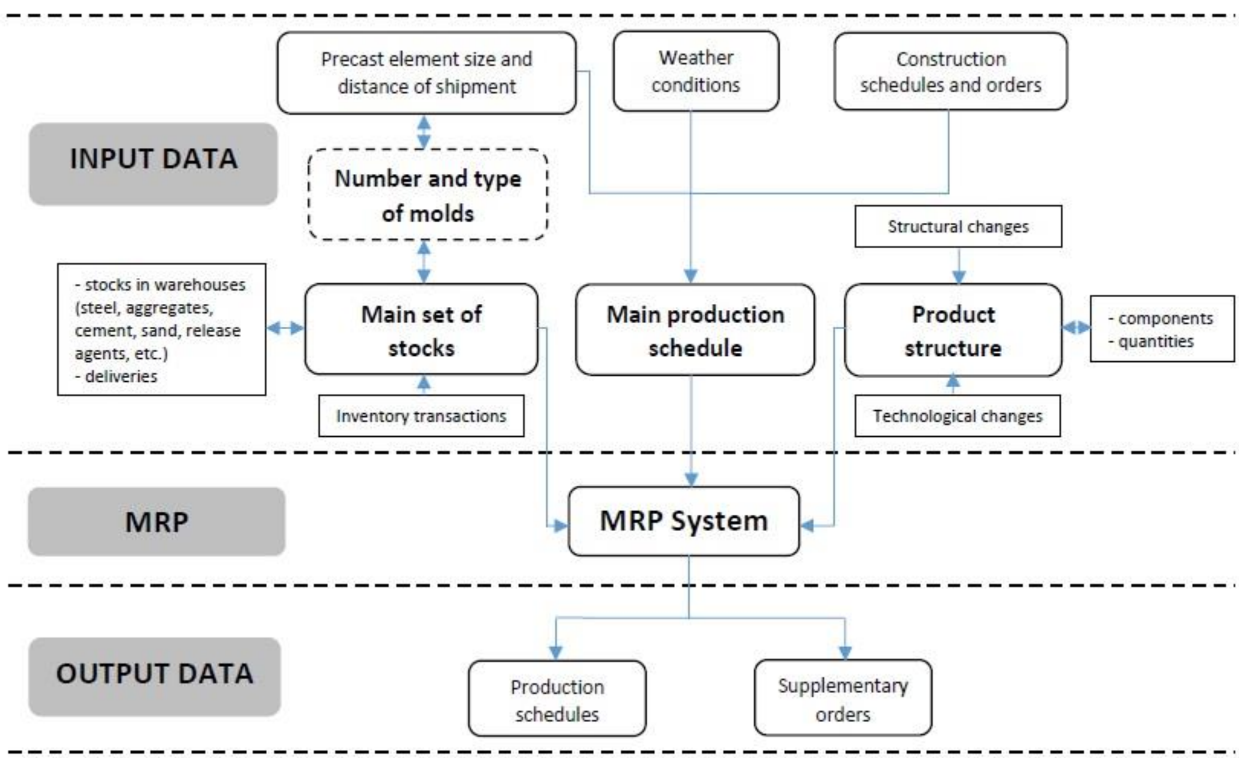

Fig. 2. MRP system for precast concrete plants.

It is also worth emphasizing the circumstance related to the securing of resources (aggregate, cement) by the impact of weather conditions in winter, causing the need to invest in the appropriate infrastructure to handle these resources (thermally insulated silos and tanks). Moreover, a lower temperature in the production hall may affect technological processes, e.g. the need for longer curing processing of concrete or increase costs, e.g. through the need to use concrete admixtures or heaters. Precast concrete elements do not have such a complex structure as, for example, electronic machines or devices. They require, however, the use of a large number of steel molds [12], which largely determines the production capacity. The molds constitute the production resource of the plant. Considering the high purchase cost of the molds, their use in the production processes should be maximized, on the one hand. On the other hand, a wide and diverse range of orders makes it necessary to use steel molds adapted to be retooled [2]. Such an approach makes it possible to reduce the number of molds and costs, however, it slows down the production process and makes it necessary to organize additional space in the plant for their retooling. The difficulties in shipping of precast elements are also not without significance, which due to their large size and mass require over-standard transport means and often additional time. The MRP system for the production of precast concrete elements is presented in Figure 2.
In order to illustrate the operation of the MRP system below, an example production of two different types of railway sleepers marked as A and B is presented. The product structure is shown in Figure 3.

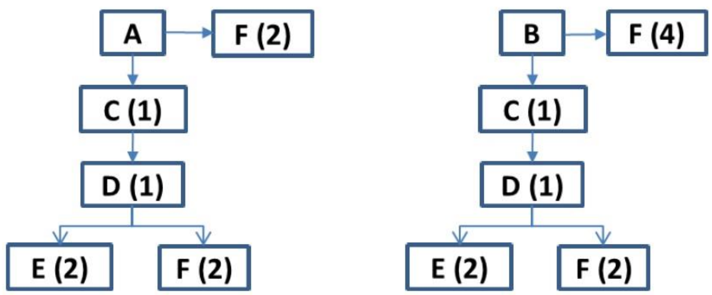

Fig. 3. Structure of prefabricated railway sleeper type I (A) and type II (B) - examples.

Letters denote further levels in the product structure that are:
A – railway sleeper type I,
B – railway sleeper type II,
C – mold equipped with reinforcement basket,
D – reinforcement basket,
E – reinforcing steel,
F - steel accessories (fastening screws, nuts, rings, dowels, etc.).

The number of given elements, in this case, they are sets of the assortment described above, included in the position performed at a higher level is indicated in brackets. On day 7 and 11, the production of A and B railway sleepers was planned. The main production schedule, stocks at the end of the first day and delivery periods are presented in Table 1.

Table 1. Main production schedule, stocks at the end of the first day and delivery periods.

Product, subassembly, part	Day					Stock at the end of the first day	Delivery period (in days)
	7	8	9	10	11		
A	660	-	-	-	560	60	2
B	480	-	-	-	490	80	2
C	-	-	-	-	-	20	1
D	-	-	-	-	-	30	1
E	-	-	-	-	-	40	1
F	-	-	-	-	-	50	1

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The production and delivery schedule resulting from the MRP system is presented in Table 2. In the case of A and B products, the order includes the supply of an appropriate amount of aggregate, sand, cement, and additives needed to produce a concrete mix for both types of railway sleepers.

Table 2. Production and delivery schedule for products A and B, subassemblies C and D and parts E and F.

Product, subassembly, part	Specification	Day										Delivery period (in days)
		2	3	4	5	6	7	8	9	10	11	
	Gross demand						660				560	
	Stock						60					
A	Net demand						600					2
	Supply						600					
	Order				600							
	Gross demand						480				490	
	Stock						80					
B	Net demand						400					2
	Supply						400					
	Order				400							
	Gross demand				1000							
	Stock				20							
C	Net demand				980							1
	Supply				980							
	Order			980								
	Gross demand			980								
	Stock			30								
D	Net demand			950								1
	Supply			950								
	Order		950									
	Gross demand		1900									
	Stock		40									
E	Net demand		1860									1
	Supply		1860									
	Order	1860										
	Gross demand		1900		2800							
	Stock		50									
F	Net demand		1850		2800							1
	Supply		1850		2800							
	Order	1850		2800								

4. MRP system in Lean Concept

The use of the MRP system contributes to reducing the costs of storing stocks related to the supply of raw materials and "on time" production in accordance with the main schedule production. The system also allows the elimination of unnecessary stocks, contributes to timely production, improves flexibility in terms of order fulfillment. Other advantages include creating the basis for long-term planning, which positively affects the development of a company, its usefulness in the case of batch production or the implementation of product assembly processes, and the ease of coordinating ordering processes throughout the enterprise. The MRP system fits very well into the "Just-in-Time" concept and also intends to integrate the procurement processes between construction sites and precast concrete plants. Accurate planning of orders and deliveries is also a great advantage for construction companies, as it facilitates the development of schedules and the implementation of construction contracts based on them.

The MRP system also has disadvantages, including the need to use high-quality computer equipment, in particular when there is a very large number of orders, and the structural complexity of products is considerable. It should be emphasized, however, that unlike many other industries, construction production is characterized by a relatively small complexity of products. In addition, a large part of the manufactured products is not in full readiness, which means the transfer of many activities to construction sites, for example, the on-site installation of window and door frames in prefabricated wall elements. Other potential disadvantages include the risk of increasing the costs of placing orders and transport resulting from the reduction of stocks. At this point, however, it should be noted that the increase in the volume of stocks in construction significantly affects their cost. In particular, taking into account the storage method of, for example, cement and aggregates in the period of precipitation and winter. One should also remember about the high sensitivity to periodical fluctuations in demand, which in construction depends on the general macroeconomic conditions of the economy and the season.

5. Conclusions

The MRP system is a very useful tool when planning orders and deliveries as well as production scheduling. The presented example of MRP system functioning in the production of concrete railway sleepers is not very complex and it should be noted that as a result it well illustrates the idea of the system. When increasing the diversity of the product range and the resulting increased number of components, semi-finished products, and parts, the system requires the support of advanced computer techniques. Further research in this area will lead to the development of systems reducing the participation of people in the area of the active planning of processes and control of production activities while contributing to the reduction of the risk of errors. The aim is to develop precast concrete systems based on dynamic scheduling and resource management for production plants. These systems will also accurately measure the time of tasks performed at the production site, control all employees throughout the shift, collect feedback on the production process, manage internal transport and quality control process, estimate the time required to finish new orders, manage warehouse employees as well as enable allocation of costs of production at any moment of a process, in order to maximize production and financial efficiency.

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Entrepreneurship in the Construction Industry: Key Themes and Factors to Success

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Abstract

In the dictionary entrepreneurship is defined as: “the activity of setting up a business or businesses, taking on financial risks in the hope of profit”. However, this definition does not even begin to scratch the surface for the work done in the construction industry. Construction companies are ever changing and, depending on each project that is embarked on, can be huge blessings or huge headaches. Behind every strong construction company is a strong competitor who is willing to put his or her name on the line with each and every project. These entrepreneurs are the backbone of the construction industry and without their willingness to lead the way, the industry would not be accounting for 798.10 USD Billion Gross Domestic Product in the fourth quarter of 2016. This study sets out to discover common trends and qualities that accompany the construction industry’s most successful entrepreneurs. The researcher wanted to discover what character traits and circumstances set one up for success when it comes to starting and running one’s own construction company. In order to do this, interviews were conducted with eight entrepreneurs who have built impressive businesses during their professional careers. These interviews lasted around thirty minutes each and the interviewees were given a list of questions before hand to look over and contemplate their responses. The interviews were later transcribed and combed through for further analyzation. Many conclusions were determined based off of the data that was received from the interviews. The interviewees revealed that the optimum time for someone to start a company in the construction industry is when they are in their thirties. The researcher also discovered that the entrepreneurs who had ten plus years of prior experience in the construction industry set themselves up for a greater chance at success. Furthermore, the biggest reason that each entrepreneur set out to start their own company was to have more control over their own decisions. Finally, the researcher also found that construction companies function the best when they are set up as s-corporations. Further research should look further into external reasons that entrepreneurs find success in the construction industry. Some of these factors might include overall industry health, key competitors or potential clients opening or closing their businesses.

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Keywords: Entrepreneurship; Business; Construction; Contracting; Success

1. Introduction

1.1. Research Rational

Entrepreneurship in the United States is the practice of creating and running a business that contributes to the gross domestic product. Entrepreneurship is the backbone of the United States economy. Any company that has ever existed was started by someone at some point in time. Without entrepreneurship as the sole focus in our country, our economy would be non-existent. According to Inc.com contributor Leigh Buchanan, a new study has found that the United States currently has 27 million entrepreneurs in its ranks. That puts entrepreneurs at around 14% of the general population in the United States. When you consider the number of American citizens that these 27 million entrepreneurs put to work, the numbers can become even more astounding. According to the United States Bureau of Labor Statistics, in the year

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2015 there were 3,022,581 jobs created from new business start-ups that were less than one-year-old. Because entrepreneurship has such a large amount of impact it is imperative that we give entrepreneurship the resources and research that it deserves. The construction industry is one of the more rewarding industries an entrepreneur can decide to perfect his or her craft. Unlike some industries, the construction industry truly does reward an honest day's work.

However, the fact that there are 27 million American citizens who categorize themselves as an entrepreneur does not mean that starting and running a successful business comes easy. In fact, starting a company can be one of the most challenging tasks any person could set out to accomplish. The pressures to succeed can be unbearable at times. Contributor for Inc.com, Jessica Bruder, explains that entrepreneurs experience much higher levels of anxiety than typical employees who work for them. According to the United States Bureau of Labor Statistics only 25.4% of construction companies that were formed in the year 2004 were still in operation ten years later. With only a quarter success rate, starting a construction company can be a daunting task in the United States. The question is, what about that 25.4% is different than the rest of the companies that failed? Was there some common ground in the quarter that succeeded verse the rest? If there is a common ground among those companies, how can that be taught or copied for firms who wish to start a business from the ground up in the future? All of these questions and more are worth looking into and seeking answers for. The future of the construction industry depends on the start-up of local trade companies looking to make a name for themselves. The future of development in the United States depends on new general contracting firms pricing jobs competitively in order to get a start on their own. There are numerous stories that are waiting to be told and unveiled in the construction industry. There are many founders who are waiting to share the stories of how they built their businesses from the ground up and pushed through the times when others felt things were turning out to be a lost cause.

1.2. Research Aim

The aim of this study is to investigate what character traits, qualities, abilities, opportunities and knowledge it takes to become a successful entrepreneur in the South-eastern United States construction industry. This is better defined in the bulleted items below:

- Identify an ideal age for an entrepreneur to start a construction firm
- Identify how much experience is enough for an entrepreneur to find success at starting a construction firm
- To understand what drives construction entrepreneurship and what makes construction professionals start their own company

1.3. Research Objectives

The objectives of this research include:

- To investigate the personality types of successful construction entrepreneurs in the construction industry
- To discover the key ideas and themes that arise in the entrepreneurial process
- To assess common road blocks in the entrepreneur's path toward success in the construction industry
- To evaluate the best source of financing for start-up costs in the construction industry
- To determine best strategy for establishing a strong client base in the start-up phase

1.4. Key Questions

1. What character traits do successful entrepreneurs in the construction industry possess? Are these character traits taught or learned?
2. How do the majority of the successful entrepreneurs get their start in the construction industry?
3. How many years of experience do most entrepreneurs have when they decide to start their own firm?
4. How do most entrepreneurs go about funding their construction firm in the start-up phase of the company?
5. What was the hardest part about starting a construction firm and how did they work to overcome that obstacle?
6. Where did the majority of the successful entrepreneurs find their first clients?

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1.5. Scope

The research scope will be limited as follows:

- Commercial general contractors, subcontractors, material suppliers, and homebuilders
- U.S. based companies
- Firms size ranging from $100,000 to $150 million in annual revenue

2. Literature Review

There were many "stand out" themes that arose in the process of working through these publications. One that you might expect in the research area of entrepreneurship is the importance of passion for one's work. Entrepreneurs must possess a passion for the work that they perform [1]. If you are not passionate about what you are pursuing, then you will not have the commitment to make it through the start-up of that venture. In fact, it is extremely evident that entrepreneurial commitment is strongly tied to how passionate the entrepreneur is about his or her business. There has to be a strong emotional connection to the business if it is going to make it through the toughest of times in the start-up phase of that company [2, 3].

Another interesting finding is that there are certain qualities that make entrepreneurs different from the average company or corporate employee. When studying the qualities that most entrepreneurs have, the research says that entrepreneurs tend to be more have more self-efficacy, opportunity recognition, perseverance, human and social capital, and social skills. It is also interesting that entrepreneurs who lacked these qualities but still pursued their ventures any way tended to be less successful than those entrepreneurs who had these qualities [4].

One of the biggest factors that played into entrepreneurial success was the ability to successful exercise strong social skills. Entrepreneurs must have extensive social ability. Studies found that entrepreneurs who had strong social capital and were able to leverage that capital to their advantage were some of the most successful [4]. It was also noted in these publications that people with stronger social capital were more likely to notice entrepreneurial opportunities. The research found that the stronger an entrepreneur's social capital is, the more likely they are going to recognize entrepreneurial opportunities and seek out these opportunities by mobilizing some of their external resources. There was also a positive relationship with external resources and previous entrepreneurial experience. Entrepreneurs who had previous experience in the arena of entrepreneurship and management not only had stronger social capital at their disposal but they also had more resources to take advantage of the opportunities that they recognized [5].

Another major topic that was touched on in these publications was the process of new start-up growth and what sort of factors play into that process. It was noted that there are many barriers to new ventures being able to grow and expand their operations. Some of the most evident included: high costs of raising capital, legal system & fiscal policy regulations, strong competition, grey markets, low access to human capital, and the suppliers having control over prices. These barriers not only prevented growth but also in some cases prevented start-ups from even forming in the first place [6]. Another topic that was discussed in the area of growth was the importance of innovation and the role that innovation plays in developing a company. It is important to never stop innovating as a business if the goal is to succeed in business. Two other important factors to growth of small start-ups are making sure to learn from external sources outside the firm and being open to changing investment decisions as the firm finds growth [7].

Overall the articles gave a very strong overview of the arena of entrepreneurship and what some of the themes are right now. Obviously, there is plenty of room to pursue further research in many of these areas; specifically, in the construction industry.

3. Research Methodology

In order to better understand the subject matter and work to develop some frame work, the initial research was carried out through literature review. Themes and ideas were developed through published scholarly articles.

The second step taken for was to reach out to company founders and request their participation in the interview. A set of 18 interview questions was asked to the selected sample. The sample with descriptions can be found in the appendices at the end of the report. The interview questions are as follows:

- What services does your company provide?
- How old were you when you started your construction firm?
- How many years of experience did you have prior to starting your company?
- What made you want to start your own company?

- Have you seen those ambitions realized?
- What is the best part of owning your own company?
- What was the hardest part about starting your own construction company?
- Where did you get your start-up capital?
- How did you go about finding your first project(s)?
- How is your company structured?
- What sister companies do you own/have?
- What made you structure your company how you did?
- What was your choice of entity and why?
- What relationships proved to be the most useful when it came to the success of your construction company?
- What character traits do you have that have helped you run your own business?
- How has starting your own company affected your personal life?
- What transition plans do you have for your company?
- If you could go back would you start your own company again? Why or why not?

As one might see, the interview questions are very broad and open ended so that the interviewee is drawn to share as much as possible about their experience starting their own construction firm. The interviews were recorded for transcription. The recording took place on an iPhone and was saved in a .mp3 file format.

During the transcription of the interviews, notes were taken of the common themes and buzz words that stick out. These were organized with a shortlist to get a better idea of what the data contains. This also helped reduce some of the unnecessary data that is inevitably collected with every interview.

Once the transcriptions were complete, the data was imported into Atlas.ti. Buzzwords will be isolated and coded. Once all of the coding was is in place the data was be mined for common themes and topics that arose in the interviews. This helped determine if there were common themes that conclusions could be drawn form.

Once these common themes were determined, the quantitative data from the coding allowed the use of graphs, tables, and matrix to represent the data. This gave a better and quicker understanding of what the interviews revealed about entrepreneurs and the process of starting a construction firm [8].

Finally, once the visuals were created and complete, conclusions could be drawn about the data. Summarizing the interviews highlighting key points and themes also took place in this report.

4. Results and Discussion

The interviews were imported into a software called Atlas.ti for further analyzation. In this software, the researcher is able to code the data which helps group and identify common themes and ideas that arose during the collection process. Some of the major themes identified are represented in graphs below.

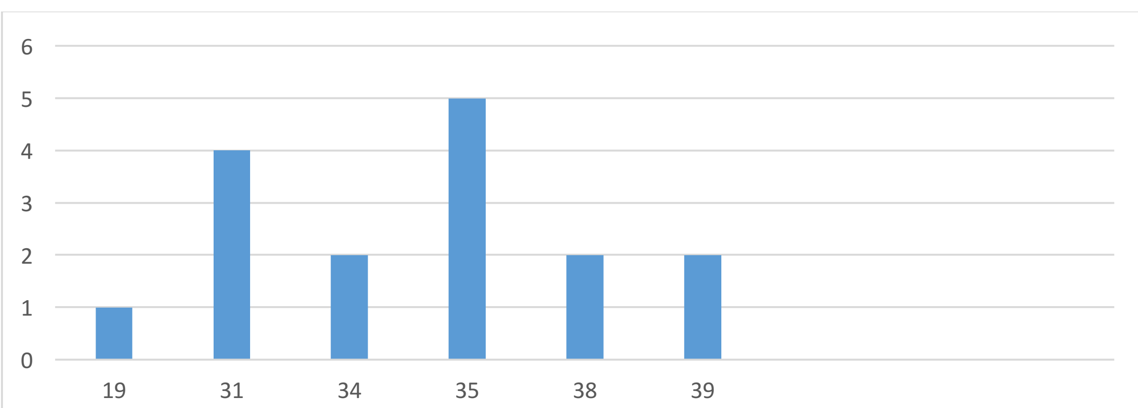

Figure 1 - Age When Starting Company

While one entrepreneur, a home builder, started his company while he was still in college at the age of 19, all of the others were in their 30s (Figure 1). A trend that most respondents echoed the same sentiment – that you needed about ten years of experience before embarking on your own. After working for another construction firm for 10 years Mr.

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A decided it was time to strike out on his own. Mr. A was 31 at the time. Mr. B said "Well, I always had an entrepreneurial spirit, even back in high school. I mean, there were things I did, so from early on, even during high school, and through college, I took on projects of different types of things that tended to be more entrepreneur than working at a wage job, so it just seemed to make sense, and obviously I wanted to do it, but I went to work for someone else out of school and gained the experience that I thought I needed to do it, and always felt like if the opportunity ever came up, I was going to do it, and ended up doing it at age 35". Mr. C noted "I got into the industry straight out of college, and what is probably important for this interview and for your perspective, is that when I got out of business school at Emory University, I had a burning entrepreneurial spirit. Just unsettled and driven to build a fine business of some kind. And I knew that I could produce sales. I knew that had the personality to go sell anything that I was interested in selling… I meet a lot of people that do it, and people do it for different reasons, but not all necessarily the right reasons, I don't think. But mine was out of pure desire and dedication to do it and enjoy the experience and the challenges that come with it"

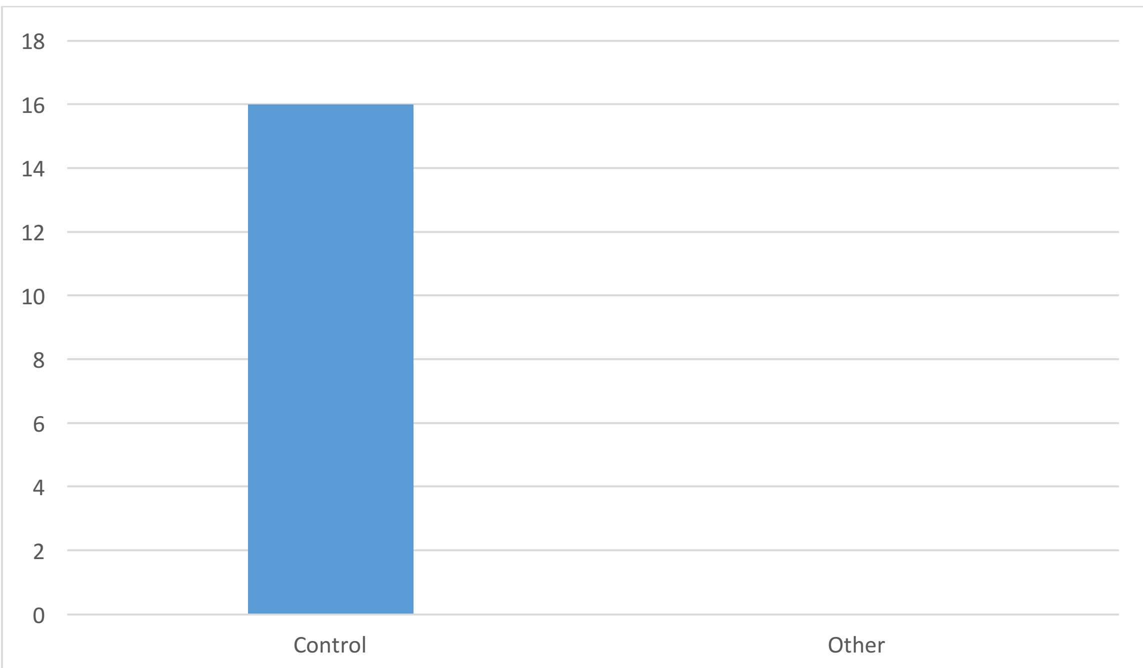

Figure 2 - Reason for Starting Company

One of the questions that received unanimous responses revolved around why they wanted to start their own business (Figure 2). The responses all had the word "control" in their answers. As Mr. D stated "I mean it's your company and you have an immediate impact of the decisions that you make. It's your dollars. It's your equity. It's your name. It's your brand. It's your reputation on the line every day. You can't blame anybody else if something happens other than yourself. When your name is on the company, it's hard for you to think of it any differently than that".

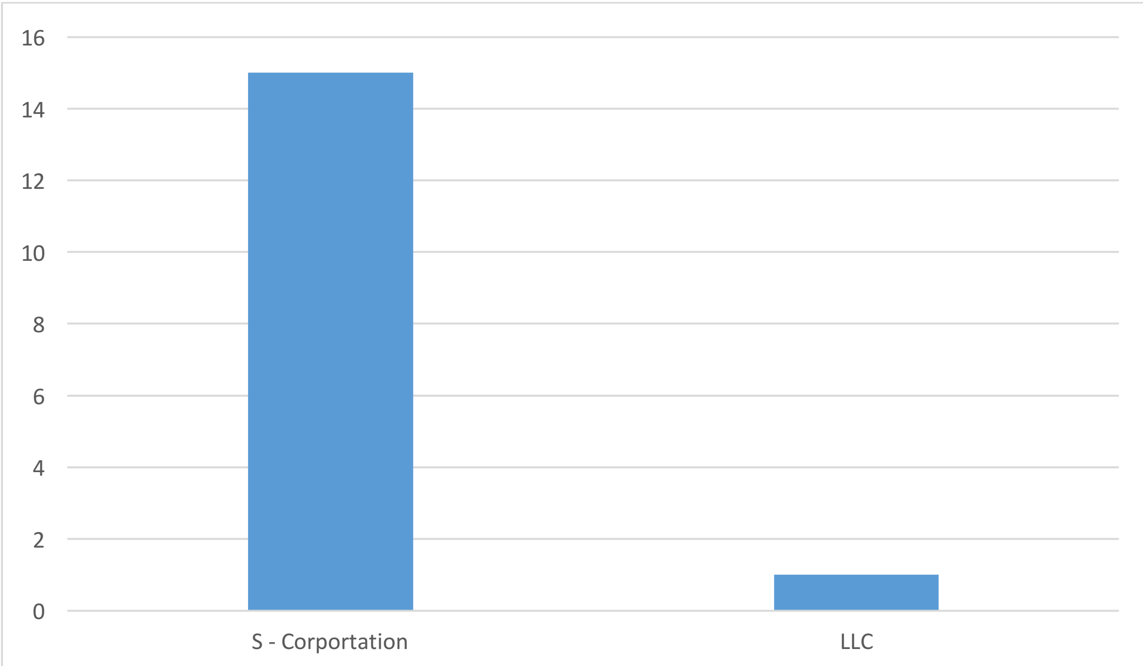

Figure 3 - Choice of Entity

One of the first decision any entrepreneur must make is the type of legal entity to choose. Under the current U.S. tax system, the most logical choices are an S-corporation or a limited liability company. Both offer the owners liability protection for their personal assets and are "flow through" entities meaning they are only taxed at the individual level and not at the entity level [9]. Figure 3 illustrates that all those interviewed had chosen S-corporations or LLCs as their choice of entity.

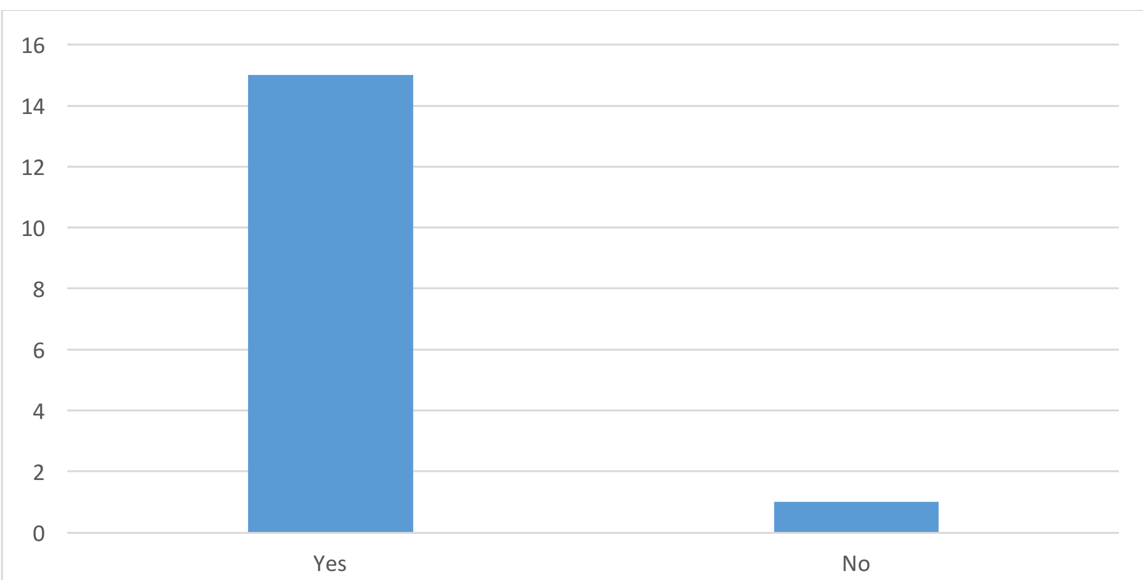

Figure 4 - Would You Do It Again?

Another area of research explored the entrepreneur's willingness to take the same steps if they had a chance to do it over again. Again, the respondents were near unanimous in their responses. Mr. E noted "I would do it again. I've enjoyed it for one, but the construction industry, as a whole, has very few barriers to entry in it, and so as an entrepreneur, it's one of the, in my opinion, it's one of the easier, least capital requirement-type businesses that you can start, and get into without having to invest a lot of capital in advance of obviously getting work. My answer is that the barriers, there's little barriers to entry in general contracting, and most construction-type firms". And another stated "Yeah. Yeah, no, I'd do it all over again. I wouldn't change anything about it. I mean, there's some mistakes I made along the way, but they were all good. That's just part of my story. So, I'm happy, man. Everything's good on my end. I don't think I could ask for anything more. So, I'd do it all over again".

5. Conclusions & Recommendations

5.1. Conclusions

Based on the coding of the interviews there are a few conclusions that can be made about the data. The most obvious conclusion that can be made is that the ideal time for one to start a company in the construction industry is in their 30's. Obviously, this isn't true for every entrepreneur and every situation but for the majority this is the prime time to start a company. This is most likely because at this time in someone's life they have the experience and knowledge necessary to make it happen but also are still young enough to have time in their career to make it happen. In addition, at this time in someone's life they have usually saved enough money from working after college to finance the venture.

Another conclusion that can be drawn is that it is best for someone to have 10+ years of experience in the construction industry before deciding to strike out on their own. In the case of some of the founder's I interviewed this obviously was not true. But running a construction company without adequate experience will not last very long. 10 years gives the entrepreneur enough time to experience multiple facets of the company(ies) they worked at prior and also breeds the confidence that running one's own company requires.

In addition, it can be concluded that an S-corporation is the best choice of entity for construction companies. Although the majority of construction companies are not set up in this structure this type of set up allows for more flexibility of ownership and still protects the owners. Every company spoken with during this study was an S-corporation, with one exception. The only exception was an LLC.

Lastly, it can be concluded that the biggest reason that these entrepreneurs wanted to start their own company was to have more control over their decisions. It is true that entrepreneurship provides that type of control, however, sometimes it can be at the cost of one's professional success. Luckily, for those that participated in the interviews, that was not the case.

5.2. Recommendations

These recommendations are for those wishing to start their own construction firm:

- Work for around ten years for a contractor that is willing to teach you as much as you can learn about all facets of the business
- Start your business in your early 30s
- All relationships are important – work to establish a positive reputation in the industry
- Save as much money as you can while working for someone else, use that money to start your venture
- Start small and reinvest your profits from previous projects back into the business
- Grow slowly and manage your cash flow

5.3. Future Research

Future research could be done exploring the personalities of entrepreneurs in greater depth. Entrepreneurs could take personality tests so their strengths and weaknesses could be recorded. Also, it would be interesting to track the growth rates of their firms. Yearly revenue could be tracked year to year so growth rates could be established. Entrepreneurship is the backbone of the construction industry and it is important that academia aide it's development in younger generations.

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Exploring Opportunities in Risks of Residential Construction Projects

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Abstract

Construction industry is known for its high risks due to its complexity and vulnerability to external conditions, such as political, weather, etc., as well as project related risk factors. Even though risks may have positive or negative effects, risks have been traditionally viewed as negative aspects that should be minimized or avoided. Thus, opportunities that are actually exist and can be explored in some risks are overlooked. The current risk management process need to be made more robust and efficient to capture the possible ways of exploiting available opportunities in the risks.
This research examined risk factors associated with residential projects in Andhra Pradesh and Telangana states of India from which opportunities can be extracted and further analyzed to identify the risk (opportunity) factors that have high impact on maximizing project value, so that the current risk and opportunity management processes can be made more robust and efficient.
Questionnaire survey was conducted to assess the perceptions of project managers or chief engineers of contractor firms on the risk factors that can be transformed into opportunities in the project execution. From the result, it is found out that even though risks are considered holistically, and the perceived importance is high, the actual implementation is not effective because of the traditional threat-oriented view of the risks. In general, the probability of risks in generating opportunity is not considered to be high. However, a few risk factors could generate high benefit to the project. Eleven important opportunity factors out of 40 factors were identified based on the scores of likelihood and impact. These 11 factors were explored in depth by interviewing experts to gain understanding on the influencing aspects that enable the generation of opportunities from the risk factors and the possible benefits of each opportunity factor.

Keywords: Contractor; India; opportunity; project success; risk.

1. Introduction

Construction projects are always associated with risks due to their complexity and dynamic nature. Efficient management of risks is crucial to successfully complete a project within the project objectives of time, cost and quality. Risk management generally deals with identification of risks, assessing their impacts, and developing strategies to create smooth path to achieve project success by mitigating possible risks. However, risks are also connected with opportunities that may have the capability to improve the project value [1,2]. The concept of opportunity management in analysing risk gradually gains acceptance from practitioners and professionals with Project Management Institute (PMI) [3] defines a project risk considering its positive or negative effect on the project objective.

The opportunity aspects of risk may provide additional encouragement for practitioners to apply proper risk management as now the focus is not only on managing the negative effects but also on finding ways to see opportunities on the risk that the project is facing. This opportunity management should be integrated in the risk management process to provide overall view of risks in the project.

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The lack of clear understanding that risk can have positive and negative aspects in the traditional project management leads to misperceptions and thus consequently allows to forgone value opportunity in the project execution. Even though several risk management processes include opportunity in their definition, it is not being implemented by several practitioners because of their threat-oriented view towards risk from a long time [4]. With the above explanation, this research aims to identify and examine risk factors that have association with opportunity in the residential building projects in India.

2. Risk, uncertainty and opportunity

As risk typically links to threats, the positive aspects of risk have not been fully explored or even provoked strong debate among risk practitioners and received strong rejections from some individuals and groups [4]. However, with PMI [3] defines risk "an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more project objectives such as scope, schedule, cost, and quality," it provides strong justification to consider the opportunity aspects in the occurrence of risk in the project. With this understanding, risk is not always about threats but also includes opportunities. In line with this, Hillson [4] proposed that by extending the risk process to manage opportunities by process modification, project value maximization can be achieved by exploiting uncertainties to derive opportunities that could remarkably improve project value.

Because of the opportunity aspect that becomes a controversy in the concept of risk, the definition of risk also varies. Standard dictionaries tend to define risk only from the negative side or downside, without considering the upside [4]. The opportunity aspect also defines how risk and uncertainty are considered. When risk is only on the negative side, uncertainty covers both risk and opportunity [4]. On the other hand, there is also another perspective where uncertainty is defined as the probability that the project objectives cannot be reached. In this case, risk is the umbrella of both loss and gain [4].

Olsson [5] argued that most of the existing processes of risk management are not fully capable to manage opportunities in all phases of the project life cycle. In dealing with this, a holistic view must be developed first (as also proposed by Ward and Chapman [6]), followed by the approach to manage opportunities. Meanwhile, Hillson [7] in his study identified many advantages of including opportunity management in the risk process, such as the increase of efficiency by doing two things in one and consequently, no additional overhead in the process is needed. The process also motivated team and supported innovation and creativity in creating benefit, value and saving for the company.

Typically, there are two components of risk that need to be taken into account when analyzing risk, the probability of occurrence of the risk or the frequency of occurrence and the impact of the risk to the project objectives. A risk may have one or more sources and if it occurs, it may have one or more impacts to the project [3]. In the context of risk management, it is common to have some terminologies such as risk source, risk event and risk consequence in analyzing risks. A risk source is something that has potential to give rise to risk. It is from where a risk is originated. Many studies have explored risk sources in international construction projects [8,9,10]. Risk event is defined as an event that occurs such that the source of risk produces consequences. Therefore, a risk event should have a cause and may have consequences. Events without consequences are often referred to as near misses or close calls [11]. The consequence of the risk event that have impact on at least one of the project objectives is defined as the risk consequence. One single risk event may be capable of generating multiple consequences, which can have a positive or negative impact on the project [11].

3. Research methodology

This research is based on concept of exploring opportunities in the risks that occur in construction projects with understanding that risks have both negative and positive aspects. The focus of the research is on the residential building projects in India. Both quantitative and qualitative approaches were applied to achieve the objectives of this research.

From literature review, a total of 42 risk factors that have possibility of generating opportunities was extracted and compiled for the purpose of this research. Expert justification was conducted to verify this list of risk factors in terms of their capability of generating opportunity and suitability to the context of residential projects. Severn experts consist of two academicians with 10 years tract record and interest in risk management, and five professional at managerial level with 15 years of experience were consulted for the justification. The justification removed two risk factors from the list. Therefore, in total, there are 40 risk factors used for this research as shown in Table 1.

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After the list of risk factors was justified, they were compiled to be the final questionnaire, which consists of three sections. The first section contains questions regarding the general information of the respondents such as the age, current position, experience, number of projects involved, etc. The second section consists of questions regarding the knowledge and perception of risk and opportunity management. The last section requesting respondents to evaluate the opportunity generated by the risk factors in terms of the likelihood the risk factors generating opportunity and the magnitude of the impact of the opportunity to the project. In the assessments of these two perspectives, five-point Likert scales were employed. The scale for likelihood is 1: never, 2: rarely, 3: sometimes, 4: most likely, and 5: always. The scale for impact is 1: negligible, 2: minor, 3: medium, 4: high, and 5: very high. The impacts of the risk factors to the project objectives of time, cost, and quality were also inquired in this research. Respondents were requested to indicate in which objectives the opportunity can be generated by giving a check. However, the results and findings of this part are not discussed in the paper due to limitation in the scope.

The questionnaire survey was conducted to engineers of contractor firms in Andhra Pradesh and Telangana states of India. In obtaining reliable result for the research, engineers qualified for the survey should have minimum of five years of experience in construction sector. A total of 93 questionnaires was distributed to project managers, assistant project managers, chief engineers, and planning engineers of 46 companies. Most of the questionnaires were distributed face to face to provide opportunity to clearly explain the content of the questionnaire. A few of the questionnaires were sent by email or mail after firstly contacting and explaining the research to the targeted respondents. Some of the questionnaires were collected directly by the survey administrators. Respondents who could not finish the questionnaire at the time of survey and who received the questionnaire by mail were provided with return envelope with address and stamp on it.

Data collected from the survey was analysed to generate ranks of likelihood and impact by considering the mean values of the risk factors. These mean values were plotted to the graph to identify important risk factors in generating opportunity. A threshold of mean value of 3.0 for both likelihood and impact is used in identifying the important risk factors. Semi-structured interviews with experts were conducted to understand how the risk factors generating opportunities. Factors that influencing the generation of opportunity from the risk factors and opportunities that can be generated were the two main aspects the interviews tried to explore. The focus was on the important opportunity risk factors, which were identified based on the likelihood and impact. Five senior project managers with more than 15 years of experience in construction projects were requested for this purpose. Each interview took around one and a half hour to two hours.

4. Results and discussion

A total of 57 valid questionnaires from 33 companies were collected from the survey, representing 61% response rate. To check reliability of the collected data, Cronbach's Alpha test was applied and yielded a value of 0.912, which implies an excellent reliability. The mean values and ranks of the risk factors from the perspective of likelihood and impact are tabulated in Tables 1 and 2.

Table 1 shows that the highest mean value is 3.7 for risk factor related to the change in construction method or technology and there are only 13 risk factors, out of 40 factors, that have mean values higher than 3.0. This implies that only less than half of the risk factors have likelihood of generating positive consequences to the project with medium probability of occurrence. Many of the risk factors have less probability to be converted to be opportunity for the project benefits.

In terms of the impact of the opportunity that can be generated by the risk factors (Table 2), in general, the evaluation was slightly higher than the likelihood with three risk factors obtained mean value higher than 4.0, indicating high opportunity impact to the project. The three risk factors are political preference toward the project, construction method or technology, and top management support of the contractor. Twenty-seven risk factors can generate medium to high impact on the level of opportunity generated. Only a few of the risk factors have minor impact with inflation (mean=1.88) has the lowest degree of generating positive impact. This indicated that in general respondents considered that the opportunities in the risk factors are worth to be explored.

Many research studies have assessed the important of risk factors by considering both the degree of impact and likelihood or frequency of occurrence. This same principle was used to identify the important risk factors in generating positive aspects to the project. The likelihood and degree of positive impact of the risk factors were plotted to the graph to produce likelihood-impact matrix as shown in Fig. 1. The important opportunity risk factors were identified by those having mean values of both likelihood and impact not less than 3.0. From a total of 40 risk factors, eleven risk factors are identified as important opportunity risk factors as listed below:

Table 1. Mean values and rank of risk factors from likelihood perspective.

Factor	Mean	Std. Dev.	Rank
Change in construction methods or technology [F11]	3.74	0.44	1
Change in design [F12]	3.47	0.66	2
Change in interest rates [F4]	3.46	0.71	3
Change in performance of workers [F26]	3.25	0.87	4
Change in top management support of the contractor [F27]	3.23	0.46	5
Change in expectations or objectives of the project [F18]	3.21	0.84	6
Change in schedule by the owner [F24]	3.19	0.55	7
Change in tax rates [F3]	3.16	0.53	8
Change in project organization structure [F28]	3.11	0.79	9
Change in political preference towards the project [F7]	3.11	0.75	10
Change in government's policy related to the project [F5]	3.07	0.70	11
Fluctuation in currency rates [F2]	3.04	0.76	12
Change in scope of work [F19]	3.02	0.77	13
Change in availability of equipment [F37]	2.98	0.72	14
Change in project size [F14]	2.98	0.69	15
Change in regulations and laws related to the project [F8]	2.97	0.63	16
Change in performance of nominated subcontractor [F22]	2.95	0.69	17
Change in availability of supplier [F34]	2.81	0.52	18
Change in coordination between subcontractor and nominated subcontractor [F23]	2.79	0.49	19
Change in availability of material [F35]	2.75	0.83	20
Change in codes and standards [F9]	2.74	0.44	21
Different geological conditions [F30]	2.72	1.11	22
Change in government's attitude towards foreign investors [F6]	2.70	0.46	23
Change in project milestones [F20]	2.70	0.80	24
Change in availability of labour [F36]	2.65	0.48	25
Change in contractual relations [F10]	2.61	0.77	26
Different site conditions [F31]	2.60	0.50	27
Unexpected breakdown of machinery [F38]	2.58	0.53	28
Different cost estimation [F29]	2.56	0.57	29
Damage to site due to natural disasters [F39]	2.53	0.50	30
Change in public relations of the contractor [F32]	2.51	0.50	31
Change in staff of owner [F17]	2.51	0.50	32
Change in material [F13]	2.49	0.50	33
Change in roles and responsibilities of the contractor and nominated subcontractor [F21]	2.47	0.89	34
Change in inflation [F1]	2.39	0.67	35
Change in financial conditions of the owner [F16]	2.25	0.43	36
Change in international relations of the contractor [F33]	2.25	0.43	37
Change in financial conditions of contractor [F25]	2.25	0.83	38
Historical findings [F40]	2.14	0.88	39
Different weather conditions [F29]	2.00	0.71	40

Table 2. Mean values and rank of risk factors from degree of impact perspective.

Factor	Mean	Std. Dev.	Rank
Change in political preference towards the project [F7]	4.35	0.64	1
Change in construction methods or technology [F11]	4.25	0.43	2
Change in top management support of the contractor [F27]	4.23	0.82	3
Change in government's policy related to the project [F5]	3.72	0.45	4
Change in project organization structure [F28]	3.70	0.73	5
Change in financial conditions of the owner [F16]	3.68	0.51	6
Change in availability of supplier [F37]	3.67	0.51	7
Change in design [F12]	3.63	0.56	8
Change in availability of labour [F36]	3.61	0.56	9
Change in scope of work [F19]	3.60	0.53	10
Change in performance of nominated subcontractor [F22]	3.58	1.03	11
Change in expectations or objectives of the project [F18]	3.56	0.54	12
Change in performance of workers [F26]	3.54	0.54	13
Change in availability of equipment [F37]	3.53	0.54	14
Change in contractual relations [F10]	3.51	0.50	15
Different site conditions [F31]	3.49	0.50	16
Change in availability of material [F35]	3.47	1.09	17
Change in financial conditions of contractor [F25]	3.26	1.30	18
Change in project size [F14]	3.25	0.43	19
Different cost estimation [F15]	3.25	0.43	20
Change in material [F13]	3.23	0.46	21
Change in project milestones [F20]	3.21	0.84	22
Damage to site due to natural disasters [F39]	3.21	0.67	23
Change in regulations and laws related to the project [F8]	3.18	0.50	24
Unexpected breakdown of machinery [F38]	3.16	0.53	25
Change in interest rates [F4]	3.11	0.52	26
Change in schedule by the owner [F24]	3.09	0.61	27
Change in public relations of the contractor [F32]	3.07	0.42	28
Change in coordination between subcontractor and nominated subcontractor [F23]	3.05	0.79	29
Change in codes and standards [F9]	3.04	0.71	30
Different geological conditions [F30]	2.97	1.25	31
Different weather conditions [F29]	2.84	1.26	32
Change in staff of owner [F17]	2.77	0.85	33
Change in government's attitude towards foreign investors [F6]	2.77	0.85	34
Change in tax rates [F3]	2.51	0.50	35
Change in international relations of the contractor [F33]	2.49	0.50	36
Historical findings [F40]	2.25	0.79	37
Change in roles and responsibilities of the contractor and nominated subcontractor [F21]	2.23	1.10	38
Fluctuation in currency rates [F2]	2.21	0.49	39
Change in inflation [F1]	1.88	0.54	40

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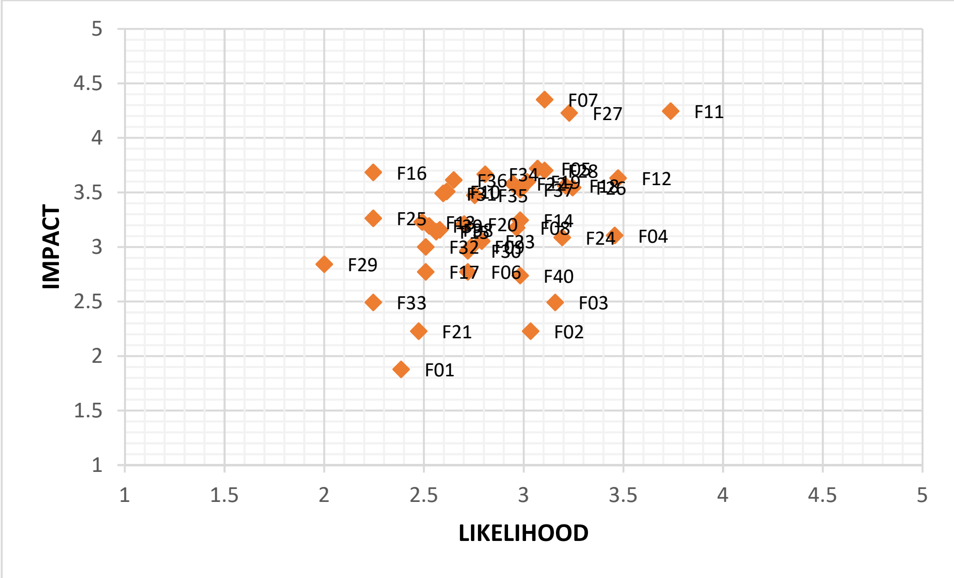

Fig. 1. Likelihood impact matrix.

1. Change in construction methods or technology [F11]
2. Change in top management support of the contractor [F27]
3. Change in political preference towards the project [F07]
4. Change in design [F12]
5. Change in performance of workers [F26]
6. Change in project organization structure [F28]
7. Change in expectations or objectives of the project [F18]
8. Change in government’s policy related to the project [F05]
9. Change in scope of work [F19]
10. Change in interest rates [F04]
11. Change in schedule by the owner [F24]

Due to the limitation of space, the results of the interviews are presented only for the first two important opportunity risk factors, i.e. change in construction methods or technology [F11] and change in top management support of the contractor [F27]. They are discussed in the following subsections.

4.1. Change in construction methods and technology [F11]

This risk factor is on the first and second ranks for likelihood and impact, respectively. The dynamic environment of construction projects facilitates the development of new construction methods or technology to increase productivity and safety. Contractors need to adapt on and adopt this new development in order to be competitive and to exploit the maximum possible benefits. Even though some of the enterprises deal it as a risk, this factor has the capability to generate opportunity, which helps in achieving the project objectives. In grabbing the opportunity from the factor, various parameters, both internal and external, have to be managed efficiently. Various influencing parameters and the exploitable benefits that can be generated from the factor are displayed in Fig. 2. The I and E symbols after influencing parameters represent the category of the parameter: internal and external, respectively.

Efficient IT knowledge of the contractor is one of the influencing parameters and is crucial in the rapidly upgrading technological environment and it helps in increasing the productivity. Management capability of the contractor is another crucial influencing parameter which is essential to deal with change and increase the productivity. When there is a change in the construction method or technology knowledge of the new method or technology is very crucial in order carry out the work smoothly without any accidents and to have superior control over the quality of work. Experience of the technical personnel who are involved in the project is another crucial parameter which helps in completing the project as per schedule or even before the schedule despite of the new method or technology. Adequacy of the availability of the plant and labour resources is also an important influencing parameter which helps in completion of the project earlier that the expected schedule.

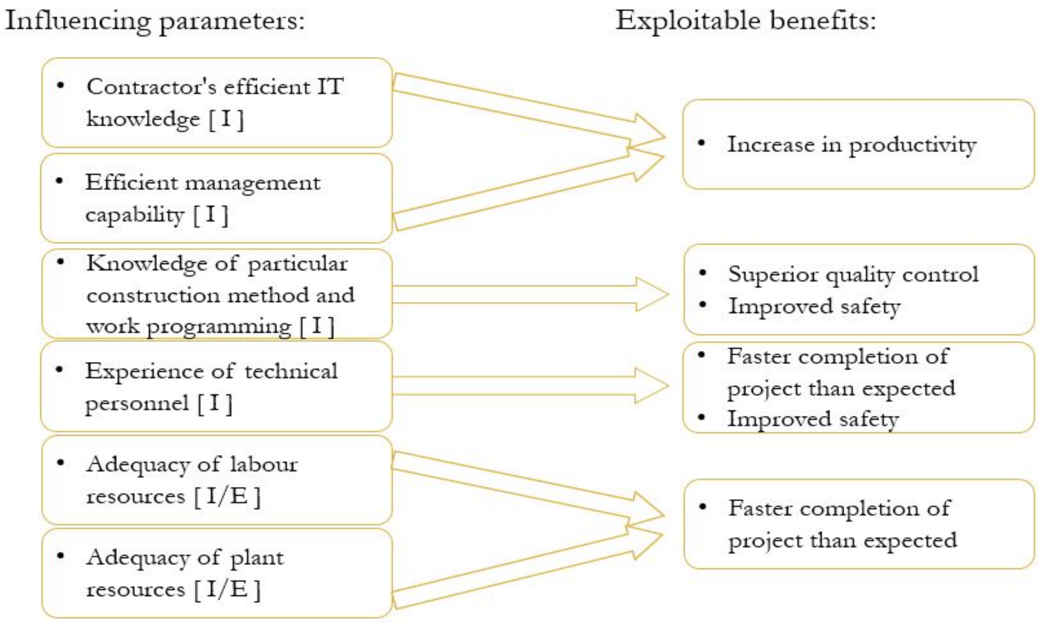

Fig. 2. Diagram explaining the influence parameters and benefits of change in construction methods and technology.

4.2. Change in top management support of the contractor [F27]

Change in top management support of the contractor is on the fifth rank in term of likelihood, but it ranks third in the degree of impact. Commitment of top management has always been found to be one of the most important factors contributing to project success by many studies. The same applies to the opportunity management in dealing with risks as long as a solid and systematic organization structure has been well developed in the company and fully integrated to the projects. This risk factor can generate positive aspects when more supports are provided from the top management to the project or when head office decentralizes some authorities to the project site. The later part can be viewed as a less support provided to the project site (risk/negative aspect) if no proper system or procedure is established on the authorities allocated to the project and no proper communication on the allocation to the project personnel.

As this factor deals directly within the contractor’s company, all influence parameters are internal parameters as depicted in Fig. 3. One of the influencing parameters is organizational structure. A supportive project organizational structure is helpful in increasing the productivity, smooth flow of the project with minimum possible threats, and generating healthy and positive relationship among the project staff. Interactive inter departmental groups in the project is another parameter that facilitates free flow of communication among the various departments in the projects and can certainly generate benefits.

Quality is one of the crucial variables in achieving the success of project and the quality management plan is not a responsibility of one department or individual thus organizational quality project plan is an important influencing parameter to make sure that each project can achieve the required quality. Proper decision-making process is always important and to exploit it, project management office (PMO), whenever it is available, should be included in the process to develop solid project procedure in monitoring and evaluating the progress to gain control over budget, schedule, and quality of the works so project execution can be done smoothly and efficiently within the project.

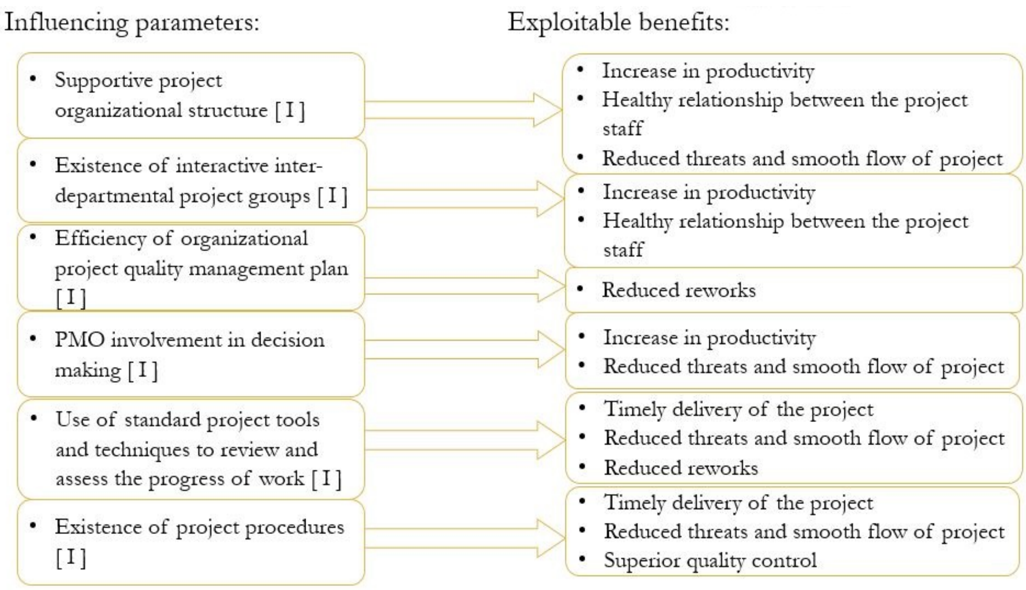

Fig. 3. Diagram explaining the influence parameters and benefits of change in top management support.

5. Conclusions

The study of opportunity in risks of residential projects in India indicated that opportunity was perceived in some risk factors but, in general, the likelihood was considered not so high. Although the probability was not high, a few of them were assessed to be able to contribute positive aspects to the project success. Eleven important opportunity risk factors were extracted based on their likelihood and impact to the project, which cover aspects related to construction methods or technology, top management support of the contractor, political preference towards the project, design, performance of workers, project organization structure, expectations or objectives of the project, government's policy related to the project, scope of work, interest rates, and schedule of project from owner. Influencing parameters and exploitable benefits were explored and explained for each of these important opportunity risk factors based on the interviews of five experts. Diagrams summarizing the interview results were developed to help practitioners adopt, optimize, and improve opportunity management in dealing with risks.

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Factors Affecting Readiness of Thai Contractor in Approaching ASEAN Economic Community (AEC)

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Abstract

According to the official establishment of the ASEAN Economic Community (AEC), there will be a free movement of products, services, investment, finance and skilled labor. Construction and related engineering services are one of the important services under the General Agreement on Trade in Services which creates both opportunities and threats to Thai contractors. Therefore, Thai contractors should examine their readiness in order to compete in the free trade market. This study aims to identify factors affecting the readiness of Thai contractors in approaching AEC. Thai contractor's factors in this study merely focus on the corporate or company level which can be classified into internal factors and external factors. Internal factors were divided into strategic factors, corporate factors, management factors, psychological factors and technical factors whereas external factors were divided into laws and regulations, AEC agreement and socio-economic issues. A research survey was conducted with a structured questionnaire. The target group was 237 contractors whose experience was in both local and ASEAN construction markets. Sample size was allocated by Taro Yamane theory of 95% reliability and the number of samples was 149. The collected data was analyzed by using descriptive and inferential statistics. Findings indicated that the relationship between internal and external factors was positive and was in the same direction. Internal factors affect Thai contractors' readiness more than external factors. The internal affecting factors of Thai contractors' readiness were technical factors, corporate factors, strategic factors, management factors, and psychological factors respectively. Meanwhile external affecting factors were socio-economic factors, laws and regulations, and AEC agreement respectively. Focused on the level of affecting factors, the highest was the technical factors which comprised research and development (R&D), information technology (IT) and construction technology. Those affecting factors were mostly located at the organizational level. Therefore, strategic policy and planning should be initiated for those Thai contractors who need to play their roles in the ASEAN construction market.

Keywords: ASEAN Economic Community (AEC); Affecting Factors; Readiness; Thai Contractors

1. Introduction

The Association of Southeast Asian Nations or ASEAN comprises 10 member countries, namely Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Vietnam. The official establishment of ASEAN countries is aimed at economic, social and cultural cooperation, to promote peace, security and cooperation between ASEAN and foreign countries. It also promotes economic prosperity and quality of life for the people. ASEAN is a group of countries which can develop together in the economic, political and social as like the European Union. The integration of the ASEAN community is a powerful force for global competition.

The establishment of the ASEAN Economic Community (AEC) in 2015 was a major milestone in the regional economic integration agenda of ASEAN, offering opportunities in the form of a huge market of US$2.6 trillion and over 622 million people. In 2014, AEC was collectively the third largest economy in Asia and the seventh largest in the world. [1] The AEC is a major pillar force driving economic cooperation in the ASEAN countries which will lead

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to a single market and a joint base for production. There will be free movement of products, services, investment, finance and skilled labor. Consumers will be able to choose among the variety of products and services and people can travel more conveniently and freely in the ASEAN countries. [2] There are no obstacles among the movement of goods and services. Therefore such liberalization will create both advantage and disadvantage to the investor or entrepreneur depending on the potential of each country.

In the negotiation of liberalization of services under the General Agreement on Trade in Services (GATS), there are 12 types of service sectors: 1) Business services 2) Communication services 3) Construction and related engineering services 4) Distribution services 5) Educational services 6) Environmental services 7) Financial services 8) Health related and social services 9) Tourism and travel related services 10) Recreation, cultural and sporting services 11) Transport services and 12) Other services not included elsewhere.

The construction industry is one of the twelve service sectors under the trade liberalization agreement. The implementing of the ASEAN Economic Community in 2015 is likely to impact on the Thai construction industry in both organizations and individuals. According to this circumstance, Thai contractors should be aware of the coming competition and should examine their readiness in order to compete in the free trade market. Therefore, this study aims to identify factors affecting the readiness of Thai contractors in approaching AEC.

2. Theoretical Concepts

2.1. Definition of readiness

Readiness means state of preparedness of persons, systems, or organizations to meet a situation and carry out a planned sequence of actions. Readiness is based on thoroughness of the planning, adequacy and training of the personnel, and supply and reserve of support services or systems.[3] The business readiness for entering the international market was separated into 2 dimensions; company readiness and product readiness. The company's readiness was analyzed from the strengths and weaknesses associated with the ability of export and the level of internationalization of the organization. It was composed of six components i.e. competitiveness in the domestic market, driving force in foreign business, commitment of entrepreneurs and executives, standardization of product, knowledge and resource management skills, and experience and training.

Therefore, readiness in this study focused on company readiness which is defined as the state of preparedness of a qualified, motivated, and experienced organization that matures enough to manage human resources, budget, materials and technology, and management in order to enhance organization competitive for entering the ASEAN Economic Community.

2.2. Organizational factors of the contractors

Construction work has unique characteristics unlike other industries. The performance of construction works indicate quality of work, working time and construction costs which derive from the capability of contractors. The more efficiency the contractors operate with and manage their organizational factors, the more profitability they receive from construction work. The construction firm is a market trader. It acts as a broker of opportunities for projects and as an intermediary acquiring materials, human resources, equipment and finance to undertake those projects. [4]

Factor is one of the elements contributing to a particular result or situation. [5] Hence, the contractors' organizational factor means the element that cause contractors to achieve their goals effectively in terms of quality, time and cost.

Factors affecting the competitiveness of the construction industry are divided into 3 levels, namely nation level, company level and project level. In company level, factors are divided into five main factors, namely, strategic factor, corporate factor, management factor, technical factor and psychological factor while each main factor also divided into sub factors. Strategic factors include 4 sub factors i.e. company policy, stakeholders, power and influence and marketing strategy. Corporate factors include 4 sub factors i.e. legal and regulations, organizational structure, organizational characteristics and government impact. Management factors include 4 sub factors i.e. economic stability, financial stability, management process and operation/management. Psychological factors include 4 sub factors i.e. cultural influence, human resources, motivation and communication. While technical factors include 4 sub factors i.e. technology, information, knowledge and facility and equipment. [6]

According to the literature review, Thai contractor's organizational factors in this study merely focus on the corporate or company level which are classified into internal factors and external factors. The internal factors is classified into 5 main factors namely strategic factors, corporate factors, management factors, psychological factors and technical factors. Each main factors are also separated into sub factors and criteria respectively as shown in table 1.

Table 1. Thai contractor's internal factors.

Main Factor	Sub Factor	Criteria
1. Strategic Factor	1.1 Organizational Policy	1.1.1 Clear policy for entering AEC
		1.1.2 Clear objective and process of work
		1.1.3 Clearly define type of construction expertise
	1.2 Cooperation Network	1.2.1 Self-reliance organization
		1.2.2 Establish networking among construction stakeholder
		1.2.3 Management attitude of shareholder are in the same direction
	1.3 Marketing Strategy	1.3.1 Plan to expand overseas construction business
		1.3.2 High competitive among contractors and relates business
		1.3.3 Increasing number of construction project
2. Corporate Factor	2.1 Organizational Model	2.1.1 Clear organizational structure and line of control
		2.1.2 Proper staff selection and recruitment system
		2.1.3 Standard payroll system
	2.2 Rules and Regulations	2.2.1 Clear rules and regulations for employee
		2.2.2 Have procedure and working instruction
		2.2.3 Have the accounting information system for decision making
	2.3 Organizational Characteristics	2.3.1 Have ability to manage organizational liquidity
		2.3.2 Satisfy with worker's productivity in every level
		2.3.3 Receive reputation and has ability to compete with foreign contractors
3. Management Factor	3.1 Management Process	3.1.1 Efficiency planning process
		3.1.2 Efficiency organizing process
		3.1.3 Efficiency controlling and monitoring process
	3.2 Project Delivery	3.2.1 Efficiency coordinating process
		3.2.2 Efficiency project delivery process
		3.2.3 Customer satisfaction in construction work
	3.3 Internal Operation	3.3.1 Construction project complete with standard quality
		3.3.2 Construction project complete within contractual schedule
		3.3.3 Construction project complete within contractual budget
4. Psychological Factor	4.1 Organizational Culture	4.1.1 Good welfare for staff and worker
		4.1.2 Good teamwork and cooperation
		4.1.3 Accident rate lower than previous year
	4.2 Human Resources	4.2.1 Effective teamwork
		4.2.2 Good attitude staff
		4.2.3 No strike of worker
	4.3 Motivation	4.3.1 Have regular promotion system
		4.3.2 Have bonus and reward system
		4.3.3 Have effective motivation for working
5. Technical Factor	5.1 Construction Technology	5.1.1 Sufficient construction machine & equipment
		5.1.2 Construction equipment can be used in maximum capacity
		5.1.3 Plan to updating technology and equipment

Table 1. (continued)

Dimension	Main Factor	Sub Factor
	5.2 Information Technology & Communication	5.2.1 Implement IT in organization
		5.2.2 Information transfer not complicate and efficiency
		5.2.3 Efficiency information management and controlling
	5.3 Research & Development	5.3.1 Introducing innovation into organization
		5.3.2 Arrange training for human resources development
		5.3.3 Always have R & D in the organization

External factor is separated into 3 main factors namely Thai laws and regulations, AEC agreement and socio-economic issues which are divided into criteria as shown in table 2.

Table 2. External factors of Thai contractors

Main Factor	Criteria
1. Thai laws and regulations	1.1 Construction laws and regulations
	1.2 Laws and regulations for foreign profession and investor
	1.3 Government policy on construction business
2. AEC agreement	2.1 Investment profile compare to other ASEAN countries
	2.2 Government preparation for entering ASEAN economic community
	2.3 Terms and conditions for enhance competitiveness of Thai contractors
3. Socio-economic Issues	3.1 Economic situation
	3.2 Social and culture
	3.3 Political stability

3. Research Methodology

This study is a survey research which was conducted with a structured questionnaire. The target group was 237 Thai contractors whose experience was in both local and ASEAN construction market. Sample size was allocated by Taro Yamane theory of 95% reliability and the number of samples was 149 contractors. The samples derived by using simple random sampling. The respondents of this study were 76 contractors or 51.01% of the total. After verifying the completeness of collected questionnaires, data was analyzed by using descriptive and inferential statistics.

The rating scale is used in the questionnaire to assess the extent to which the respondents rate their opinions from the highest to the lowest of the five levels of Likert scale. To analyze the respondent's opinion, questionnaires were interpreted by stratified calculation as follows;

4.51 - 5.00 means most agree
3.51 - 4.50 means high agree
2.51 - 3.50 means moderate
1.51 - 2.50 means low agree
1.00 - 1.50 means least agree

In order to test the relationship between variables i.e. internal factor and external factor, Pearson's Correlation Coefficient was used for statistically significant effects at 0.01 and 0.05. The correlation coefficient are as follows;

r is positive. both variables are related in the same direction.
r is negative. both variables are related in the opposite direction.
r = 0.00 - 0.20. very low relationship
r = 0.20 - 0.39. low relationship
r = 0.40 - 0.59. moderate relationship
r = 0.60 - 0.79. high relationship
r = 0.80 - 1.00. very high relationship

For hypothesis testing, multiple regression analysis was used to analyze the variables that predict the readiness of Thai contractor in approaching the ASEAN economic community.

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4. Results and Discussion

The results of this study are presented to support the objectives and hypotheses of the study which is separated into 4 parts as follows:

4.1. Current state of Thai contractors' organizational factors

From the analysis of the internal factors, the five main factors of the organization can be classified as shown in fig. 1. This study found that the overall current internal factors of Thai contractors was at a high level (mean = 3.93). Considering the main factors of internal factors, it was found that the management factor was the highest at the high level (mean = 4.12), the corporate factor was at the high level (mean = 4.01), the psychological factor was at high level (mean = 3.89), the technical factor was at high level (mean = 3.83), and the least was the strategic factor with a high level (mean = 3.80).

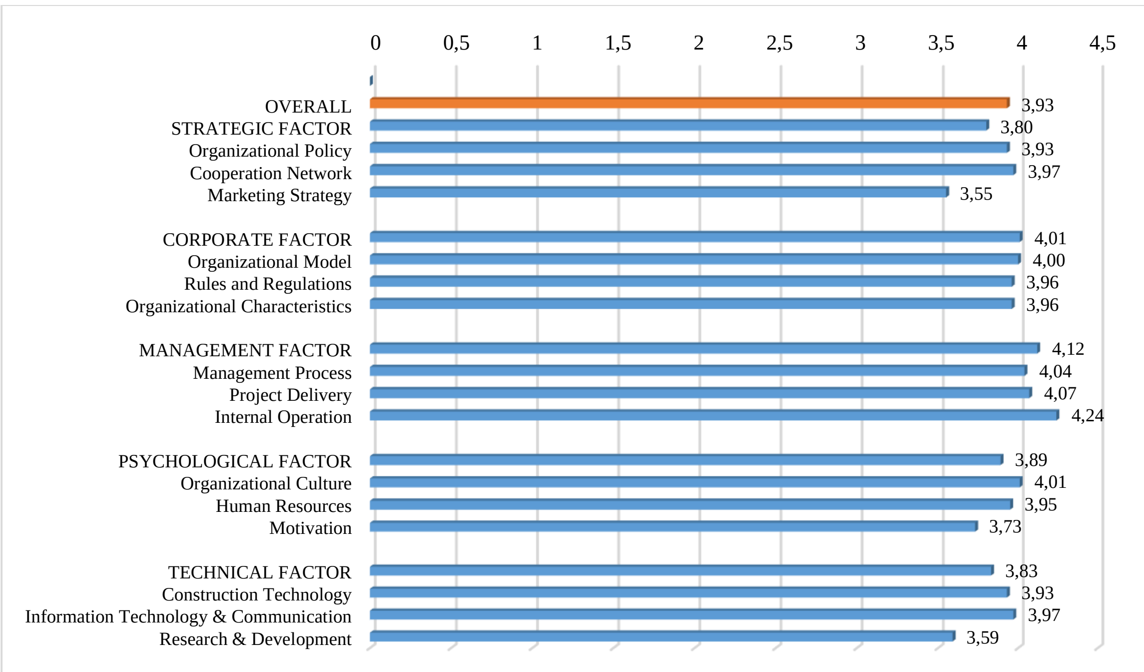

Fig. 1. Current state of Thai contractors' internal factors.

In analyzing the external factors of Thai contractors, this study found that the overall external factors of the contractor was at a moderate level (mean = 3.33). Considering the main factors of external aspects, it was found that Thai laws and regulations was the highest at moderate level (mean = 3.38), AEC agreement was at moderate level while the least was socio-economic issues with a moderate level (mean = 3.24) as shown in fig.2.

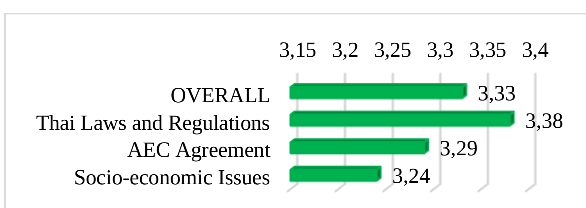

Fig. 2. Current state of Thai contractors' external factors.

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4.2. Organizational factors affecting the readiness of Thai contractors

An analysis of organizational factors affecting the readiness of Thai contractors use a Pearson's product moment correlation to identify the relationship of two independent variables by testing of the hypotheses H1 and H2 as follows.

H1: Internal factors and external factors are correlated with the readiness of Thai contractors in approaching ASEAN economic community.

Table 3 Correlation coefficient between organizational factor and the readiness of Thai contractors. .

Variables	Correlation coefficient (r)	*p*
Internal factors	0.472**	.000
External factors	0.279*	.015

** 0.01 significant, * 0.05 significant

From table 3, analysis of the organizational factor and the readiness of Thai contractors found that the relationship between internal and external factors was a positive correlation (+). It is indicated that internal and external factors related in the same direction as the readiness. Internal factors affected organizational readiness more than external factors. Internal factors were correlated with the readiness of the Thai contractors at a moderate level (r = 0.472) with statistically significant at 0.01, while the external aspects were correlated with the readiness of the Thai contractors at low level (r = 0.279) with statistically significant at 0.05.

H2: Internal factors i.e. strategic factors, corporate factors, management factors, psychological factors and technical factors are correlated with the readiness of Thai contractors in approaching ASEAN economic community.

Table 4 Correlation coefficient between internal factors and the readiness of Thai contractors. .

Variables	Correlation coefficient (r)	*p*
Internal factors	0.472**	.000
Strategic factors	0.451**	.000
Corporate factors	0.462**	.000
Management factors	0.303**	.008
Psychological factors	0.280*	.014
Technical factors	0.523**	.000

** 0.01 significant, * 0.05 significant

From table 4, analysis of the main internal factors and the readiness of Thai contractors show that overall relationship of internal factors was a positive correlation (+). It indicated that the main factors related in the same direction. Considering five main factors, technical factors have most affected the contractors' readiness at moderate correlation (r = 0.523) with statistically significant at 0.01 while corporate factors affected the contractors' readiness at moderate correlation (r = 0.462), strategic factors affected the contractors' readiness at moderate correlation (r = 0.451), management factors affected the contractors' readiness at moderate correlation (r = 0.303) and psychological factors least affected the contractors' readiness at moderate correlation (r = 0.280).

Table 5 Correlation coefficient between sub factor of internal aspects and the readiness of Thai contractors. .

Variables	Correlation coefficient (r)	*p*
Strategic factors	0.451**	.000
Organizational policy	0.341**	.000
Cooperation network	0.097	.403
Marketing strategy	0.469**	.000
Corporate factors	0.462**	.000
Organizational model	0.426**	.000

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Table 5 (continued)

Variables	Correlation coefficient (r)	*p*
Organizational model	0.426**	.000
Rules & regulation	0.386**	.001
Organizational characteristics	0.422**	.000
Management factors	0.303**	.008
Management process	0.366**	.001
Project delivery	0.419**	.000
Internal operation	0.169	.143
Psychological factors	0.280*	.014
Organizational culture	0.286*	.012
Human resources	0.398**	.000
Motivation	0.403**	.000
Technical factors	0.523**	.000
Construction technology	0.375**	.000
IT & communication	0.454**	.001
Research & Development	0.505**	.000

** 0.01 significant, * 0.05 significant

Table 5 shows the correlation coefficient between sub factors of internal factors and the readiness of Thai contractors. This study found that the most affecting factors of Thai contractors was research and development (r = 0.505), the second affecting factors of Thai contractors was marketing strategy (r = 0.469), the third affecting factors of Thai contractors was IT and communication (r = 0.454) whereas organizational culture was the least affecting factor of Thai contractors.

4.3. Analysis of predicted factors of the Thai contractors' readiness

After analysis of the correlation of internal and external factors, multiple regression analysis models were run to find out whether the five main internal factors can predict the readiness of Thai contractors in approaching AEC.

Table 6 Results of multiple regression analysis.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	SE	Beta		
(Constant)	-1.235	.775		-1.593	.116
Strategic factors	.442	.174	.268	2.533	.014
Corporate factors	.189	.256	.133	.739	.463
Management factors	-.267	.234	-.167	-1.145	.256
Psychological factors	.210	.214	.145	.984	.328
Technical factors	.480	.233	.320	2.058	.043

(R^2 = 0.362, F = 7.950, Sig. = .000) Dependent variables: Readiness of Thai contractors

Significant at $p < 0.05$ level

As can be seen in table 6, unstandardized coefficients of the technical factors and strategic factors had significant positive regression weights of 0.442 and 0.480 respectively. The multiple regression equation which explain the readiness of Thai contractors is as follows;

Readiness of Thai contractors = -1.235 + 0.442 Strategic factor + 0.480 Technical factor

According to the standardized coefficient, technical factors and strategic factors also had significant positive regression weights of 0.268 and 0.320 respectively. The multiple regression equation which explains the readiness of Thai contractors is as follows;

Readiness of Thai contractors = 0.268 Strategic factor + 0.320 Technical factor

The multiple regression equation of standardized coefficient explains that the strategic factors affect the readiness of Thai contractors in approaching AEC. While controlling for technical factor, if the strategic factor produces one-fold increase, the readiness of Thai contractors also increases by 0.268. In the meantime, after controlling for the strategic factor, if the technical factor produce one-fold increase, the readiness of Thai contractors also increases by 0.320.

4.4. Discussion and conclusion

The aim of this study was to identify factors affecting the readiness of Thai contractors in approaching AEC. By analyzing the internal and external factors which affected the readiness of Thai contractors, it was revealed that internal factors affected Thai contractors' readiness more than external factors. The internal affecting factors of Thai contractors' readiness were technical factor, corporate factor, strategic factor, management factor, and psychological factors respectively. The technical factor was the highest affecting factor which comprised research and development (R&D), information technology (IT) and construction technology. Meanwhile external affecting factors were socio-economic factors, laws and regulations, and AEC agreement respectively.

Technical factors and strategic factors were the two predicted factors of Thai contractors' readiness, the more they increased their capability on technical and strategic factors, the higher level of competition they have. Therefore, strategic policy and planning should be initiated for those Thai contractors who need to play their roles in the ASEAN construction market.

Acknowledgements

This study is based upon the research of Readiness of Thai Contractors in Approaching ASEAN Economics Community (AEC) [7] which was supported by a grant from Sukhothai Thammathirat Open University. The author would like to express her sincere gratitude to all of the researchers, Associate Professor Dr. Orapan Nabangchang-Srisaowaluck, Associate Professor Siriporn Sajjanan, Dr. Aua-aree Engchanil and Mr. Rangsit Jiempunya who provided insight and expertise which greatly assisted the research.

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Factors enhancing practitioners' motivation in small local constructor in Japan

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Abstract

In public construction procurement in Japan, the designated competitive bidding had been mainly used until the middle of 2000s. This scheme has many advantages such as being able to select a reliable contractor with low transaction costs. It has a disadvantage, however, of possibility to cause collusive bidding particularly under shrinking construction investment period. To enhance transparency in procurement, the general competitive bidding has been introduced since the middle of 2000s. However, this reform seems to have been lower motivation of practitioners. Under the designated competitive bidding, many awarded vendors were able and willing to do good works as much as possible, some of which were not necessarily specified in contract documents. Price competition was not much severe, and good works were certainly led to award of the next project. Under the general competitive bidding, however, vendors are neither able nor willing to do works which are out of project scope. Price competition is now severer, and good works do not necessarily lead to award of the next project. Currently, thus, many practitioners now tend to do tasks as written in the contract document with demotivated feeling. To motivate construction practitioners, thus, becomes an urgent topic for the Japanese construction industry. This study conducted a field survey of practitioners' motivation in a successful small local constructor in Tokushima prefecture, Japan. This study identified several factors affecting motivation of local practitioners, including development and application of information and communication technology (ICT) well suited to the company and top management's attitudes to support employees. These factors enhance autonomy, competence, and relatedness of employees, which are three conditions for employees' intrinsic motivation. Employees' high motivation realized higher productivity and profit, which lead to high incentive. That is, there exists a cause and effect relationship between intrinsic motivation and incentive for company employees. The results hint a method of not only improving motivation of construction practitioners but also enhancing attractiveness of local construction industry in Japan.

Keywords: motivation; ICT; local constructor; Japan ;

1. Introduction

In public construction procurement in Japan, the designated competitive bidding had been mainly used until the middle of 2000s. This scheme has many advantages such as being able to select a reliable contractor with low transaction costs. It has a disadvantage, however, of possibility to cause collusive bidding particularly under shrinking construction investment period. To enhance transparency in procurement, the general competitive bidding has been introduced since the middle of 2000s. However, this reform seems to have been lower motivation of practitioners. Under the designated competitive bidding, many awarded vendors were able and willing to do good works as much as possible, some of which were not necessarily specified in contract document. Price competition was not much severe, and good works were certainly led to award of the next project. Under the general competitive bidding, however, vendors are neither able nor willing to do works which are out of project scope. Price competition

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is now severer, and good works do not necessarily lead to award of the next project. Currently, thus, many practitioners now tend to do tasks as written in the contract document with demotivated feeling. To motivate construction practitioners, thus, becomes an urgent topic for the Japanese construction industry.

In this paper, the authors put the light on Otake Group Co., Ltd., referred as to “Otake group” hereafter, which is located in Mugi, Tokushima prefecture in Japan. The company realizes drastic improvement in business productivity and improvement of employee's work motivation by introducing ICT (Information and Communication Technology) actively in business.

Chapter 2 describes the history and management characteristics of the Otake group, and Chapter 3 introduces the features and effects of construction using the ICT of the company. Chapter 4 briefly reviews literatures on motivation research in the field of construction management. Chapter 5 gives summary and interpretations of interviews with employees. Chapter 6 states conclusions.

2. History and management characteristics of the Otake group

This chapter describes the company's history and management characteristics based on interviews with Mr. Kii (Senior Managing Director) and Mr. Yamanishi (Managing Director) conducted on September 27 and 28, 2017.

2.1. History of Otake group

The history of Otake group begins with establishment of Otake group privately owned by Mr. Tachi Otake in Mugi in May 1921. Because of the War and the South Sea Earthquake, Mugi suffered great damage. Otake group worked hard to regenerate the area through restoration works, town development activities, and countermeasure construction works against tsunami. In April 1951, Otake Group Co., Ltd. was established to make management transparent. After that, the group actively worked on the fishing port maintenance projects ordered by Tokushima Prefecture and started receiving road construction projects ordered by the Ministry of Construction in 1965. In 1987, the group became the top contractor in terms of the value of awarded contracts of projects ordered by Tokushima prefecture and hired approximately 150 employees.

As the number of port development projects decreases due to decline in fishing catch, however, the number and value of works completed mainly of port projects in prefecture decreased sharply. Followed by a drastic cut of public investment by the Democratic Party's administration, the value of works completed continued to decrease greatly, and the number of employees was reduced to approximately 25 people. The group made desperate efforts to rebuild management of receiving projects ordered by the national government and town office and cutting executive remuneration to zero. Under such circumstances, the Great East Japan Earthquake occurred. Demand for seismic reinforcement work for port increased, and value of works completed turned to increase. Then, before the MLIT (Ministry of Land, Infrastructure, and Transport) advocated “i-construction” to all over Japan, the group discovered, invested and utilized the “trump card” for utilizing ICT. As a result of that, the group is dramatically improving work productivity and enhancing work motivation of employees.

2.2. Characteristics of management of Otake group

The current characteristics of Otake group’s managements are summarized as follows.

First, they are promoting further “in-house production,” that is, strengthening the work force in the field. There are three reasons for this: (1) outsourcing is becoming more difficult because the number of subcontractors is decreasing, (2) each employee can work anywhere if she/he has her/his own skill, and (3) an employee can feel a sense of achievement by directly involved with field operation. The second is disclosure of financial statement of the group to all employees. Its purposes are to realize transparent management and to make employees interested not only in their own affairs but also in the management of the company. The third is to return a significant portion of profits to employees. The company's management policy is “Return profits to employees as fully as possible and not accumulate as president’s private property.”

In October 2016, the group was first certified as a construction company in Chugoku/Shikoku area based on the law concerning promotion of employment of youth, “Youth Ale certified company.” In order for a company to be certified, it is necessary to meet twelve criteria. Among those criteria, it is extremely difficult for the small and medium-sized construction company to meet the criterion of “The average acquisition rate of the number of paid vacation days actually taken to the annual grant days of paid vacation for full-time employees is more than or equal to 70%, or the number of paid vacation days actually taken by full-time employees is more than or equal to 10 days on average." It is noteworthy that the Otake group, which promotes in-house production, received this certification. It also hints that the group's management policy will be a reference to the future of local small and medium-sized construction companies.

3. Characteristics of construction using Otake group's ICT Co., Ltd.

Features and effects of construction using Otake group's ICT are organized as follows [1].

- Creation of hybrid 3D data by synthesizing LandXml (earthwork 3D) and TS-Xml (roadside structure 3D)
- Introduction of Construction Terminal, "Comfortable Measurement Navigation," developed by Construction Systems Co. Ltd. and LN-100 "Pile Navigation" developed by TOPCON Co., Ltd.
  - Mount Hybrid 3D data on Comfortable Measurement Navigation
  - Pile navigation of tracking the prism automatically through Wi-Fi communication
- Survey by only an inexperienced young employee
  - Instruct the operator where and how deep she/he should excavate for foundation according to the cross section profile displayed on the tablet
  - All manual calculations become unnecessary. The tablet instantly displays all necessary information with 3D data on route data.
  - After completion of excavation for foundation, lay out of levelling using concrete, marking of formworks, and the height of the crown were measured by this young employee.
- Increase in work speed. Reduction of measurement cost to one-third of the conventional method
- Skilled engineers are freed from surveying work. As a result, they became able to conduct works at the office such as preparation of consultation documents with the client and quantity calculation, which used to be conducted after regular office hours.
- The problem of acquiring paid holidays by engineers, which was the most difficult, is being solved through work sharing with young employees.

Mr. Yamanishi said, "Now I am feeling effectiveness of reform of work life balance through using 3D data. V/C ("value to cost" inserted by the author) greatly increases by using 3D data. Creation and utilization technology of 3D design data will be a true technical power of the future civil engineering."

4. Previous study in construction management field

Mansfield & Odeh (1991) examined factors that influence the motivation of construction project members [2]. Kim et al. (2015) investigated motivation factors that affect the productivity of construction workers in each country [3]. Kvorning & Christensen (2015) clarified the process of small and medium construction company managers who are motivated to participate in the occupational health and safety program and participate. Cao et al. (2017) analyzed the factors that influence the motivation to introduce BIM into construction projects [4]. Furthermore, the index of PMBOK [5] has little motivation description, such as no motivation item. Overall, in the field of construction management, motivation research is still limited.

5. Interviews with employees and their summary and interpretations

On September 28, 2017, the authors conducted interviews towards 22 employees of Otake group regarding their motivations. The interviews were conducted dividing these employees into three groups: the first group mainly consisting of site workers, the second group mainly consisting of mid-level field management engineers, and the third group mainly consisting of young employees.

The followings are summary and interpretation of interview results.

First, some employees seem to have high intrinsic motivation, defined by Deci [6]. Particularly, young employees who conduct measurement tasks as if they play with smart phones have high intrinsic motivations. Mr. Kii and Mr. Yamanishi say, "They are never reluctant to do survey works. They hold tablets and do their works running, running, running, and running." These young employees seem to feel enjoyment of their works. Furthermore, three issues should be mentioned here. First, they do survey works alone. That is, they are given autonomy. Second, with the assistance of powerful hardware and software, their outputs were very accurate. As a result, they start feeling competence in survey works. Third, their relationship with their senior operators and engineers become better since those operators and engineers thank them for their accurate works and instructions. That is, they are feeling higher relatedness. Autonomy, competence, and relatedness are three components for intrinsic motivation. The young employees enjoy these three components.

Another player who seems to have intrinsic motivation is Mr. Yamanishi. His nick name is “IT geek.” As represented with this nick name, he looks to enjoy very much when he operates and explain the software he developed. Needless to say, he enjoys autonomy and competence. As a result of his kind teaching to young employees, he is appreciated as like the “God” by them. He is feeling closer relatedness to young employees.

There are not a few criticisms against existence of intrinsic motivation at work place. Thus, our observation that young employees and management seems to have intrinsic motivation is valuable hypothesis which needs rigorous validation.

Second, high survey performance by young employees leads to higher productivity and profit. This becomes a foundation of incentive such as higher bonus and acquisition of paid holidays. This cause and effect relationship between intrinsic motivation and incentive should be noteworthy. For most management, the objective of ICT introduction is enhancement of productivity, quality, or safety. Otake group was not exceptional. It should be mentioned, however, that, in reality enhancement of intrinsic motivation of young employees was the first impact of ICT introduction and that incentive provision was its result.

Third, the management seems to practice the principle of risk management (ISO 31000), “the objective of risk management is creation and maintenance of value.” Regarding investment in ICT, Mr. Yamanishi said, “I felt that these technologies can be used!” and proposed ICT investment to Mr. Kariya, the president. Mr. Kariya approved it. Because this was a big investment for small constructor, it may exacerbate the company's financial risk. This investment seemed a risky decision to the authors.

Two points should be mentioned here. The first point is that this large amount of ICT investment was made to create “value” of improving productivity of work. As a result of this investment, the company has created unexpected value of enhancing intrinsic motivation of young employees. The second point is that management did not perceive the financial risk associated with this investment. In other words, the financial risk associated with this investment was significantly reduced by management’s ability: their technological capability and deep insight. Therefore, this big investment seems nothing more than practicing the risk management principle: risk management for creation and maintenance of value.

Fourth, motivation structure seems able to be represented with the upside down pyramid type cone floating on the water surface like the upside down iceberg (Figure 1). The upside down pyramid is often used to represent the idea that the higher level managers support lower level managers and employees. Here support by higher level managers is considered inclusion of motivating lower level employees. As already mentioned, young employees involved with survey works have high intrinsic motivation. Their high motivations and performance are paid attention by mass media. Their “visible” motivations are supported by senior employees’ “invisible” motivations. Senior employees not only appreciate young employees’ works but also check whether there is no mistake in the data acquired by young employees. This warm appreciation and strict checking by senior employees motivates young employees to do even more accurate works. The management at the bottom of the upside down iceberg does appropriate risk management to create and maintain value, which becomes a foundation for motivation of all employees.

Work motivation might be discussed using waterfowl. Even though waterfowl looks progressing elegantly on the water surface, she/he moves her/his legs very hard. It should be noted that a) invisible motivations of senior employees and management exist in addition to visible motivations of young employees, and b) the invisible motivations and visible motivations interact each other.

Fifth, the managements are motivated to educate and develop young employees. Sources of managements’ motivation are not only their desire for company existence but also their feeling that they have been raised by the region. During the interview, Mr. Kii and Mr. Yamanishi kept repeating that they have been raised by the region so that they should and want to return to the region. Education and development of young employees contributes to not only stabilization of the company but also sustainable development of the region.

As described previously, Otake group had 150 employees at the peak time but only 25 people at the hardest time. Even the business of a constructor with such a long history is highly uncertain. The management seems to sincerely wish that employees can survive in other company even if they should leave the company. This wish seems a fundamental reason to motivate employees in Otake group.

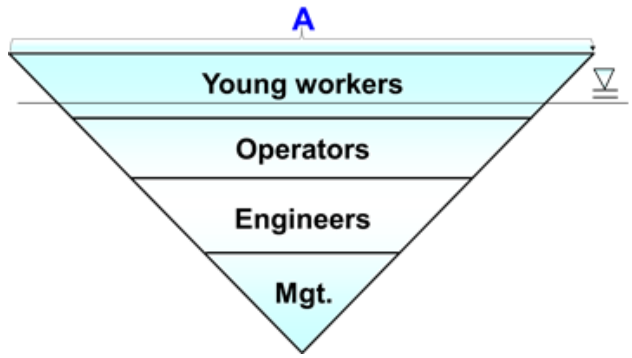

Fig. 1. Upside down iceberg.

6. Conclusions

To motivate construction practitioners, thus, becomes an urgent topic for the Japanese construction industry.

In this paper, the authors put the light on Otake Group Co., Ltd., referred as to "Otake group" hereafter, which is located in Mugi, Tokushima prefecture in Japan. The company realizes drastic improvement in business productivity and improvement of employee's work motivation by introducing ICT (Information and Communication Technology) actively in business.

First, some employees seem to have high intrinsic motivation, defined by Deci. They seem to enjoy autonomy, competence, and relatedness, which are three components for intrinsic motivation. There are not a few criticisms against existence of intrinsic motivation at work place. Thus, our observation that young employees and management seems to have intrinsic motivation is valuable hypothesis which needs rigorous validation.

Second, high survey performance by young employees leads to higher productivity and profit. This becomes a foundation of incentive such as higher bonus and acquisition of paid holidays. This cause and effect relationship between intrinsic motivation and incentive should be noteworthy.

Third, the management seems to practice the principle of risk management (ISO 31000), "the objective of risk management is creation and maintenance of value." The large amount of ICT investment was made to create "value" of improving productivity of work. The financial risk associated with this investment was significantly reduced by management's ability: their technological capability and deep insight.

Fourth, motivation structure seems able to be represented with the upside down pyramid type cone floating on the water surface like the upside down iceberg. Young employees' "visible" motivations are supported by senior employees' "invisible" motivations. Work motivation might be discussed using waterfowl. Even though waterfowl looks progressing elegantly on the water surface, she/he moves her/his legs very hard. It should be noted that a) invisible motivations of senior employees and management exist in addition to visible motivations of young employees, and b) the invisible motivations and visible motivations interact each other.

Fifth, the managements are motivated to educate and develop young employees. Sources of managements' motivation are not only their desire for company existence but also their feeling that they have been raised by the region. Education and development of young employees contributes to not only stabilization of the company but also sustainable development of the region. Even the business of a constructor with such a long history is highly uncertain. The management seems to sincerely wish that employees can survive in other company even if they should leave the company. This wish seems a fundamental reason to motivate employees in Otake group.

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Firm's Characteristics as a Determinant of Firm's Growth

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Abstract

There is increasing evidence of the role firm characteristics plays in recognition of a firm within its niche environment. However, much has not been explored into firm's characteristics to ascertain the full benefits associated with that feature. This study, therefore, explored into firm's characteristics as a determinant of firm's growth. Primary data through the used of the questionnaire assisted in gathering relevant information from 20 sampled small and medium-sized construction firms randomly selected within the Greater region of Accra in Ghana and its sub-metropolis. Data were analysed with the aid of statistical package for social sciences (SPSS) version 24 using exploratory factor analysis technique. Findings from the study revealed significant factors that influence firm's characteristics and further contribute to the entire growth of a firm. This study also established that small and medium-size construction firm's growth is impacted by vigorous characteristic features which encourage and bring about integrated results the firms and the entire industry.

Keywords: characteristics, determinant, firm, growth ;

1. Introduction

The performance and the role of small and medium-sized construction (SMEs) in any economy are not limited to the relevant provision of employment, facilitation of socio-economic infrastructural needs and poverty reduction but also the entire growth of the firm. Growth among these SMEs varies from nations and among industries and may be measured in several levels including sales employees growth over a particular period [1]. The growth of the firm is also defined in the various context in literature signifying that growth has no precise definition. According to [2], firm's growth is driven by the current microeconomic issues such as its organisational outcome resulting from the amalgamations of firm-specific resources and capabilities. [3] similarly stressed that growth determinants of firms are categorised into three integrated themes namely: organisational, environmental and individual determinants. These identifiable items influence firms to grow. [4] however argued that one of the essential drivers of sustainable growth in developing countries is firm's growth. As a result, comprehending firm's growth has now become a great concern for researchers and policymakers. Therefore identifying the channel that promotes small and medium-sized firm's growth that will provide the basis to influence strategic direction to create the environment and the required initiatives to help other informal sectors is essential. Despite the established numerous of determinants of firm's growth among SMEs, there is still a dearth of firm's characteristics as a determinant of firm's growth among construction SMEs which influence growth. This study explores the organisational determinant which is also referred to as firm characteristics as a determinant of firm's growth. Further, this study adds to the existing stockpile of knowledge by identifying the firm's characteristics of a company that results in growth so that both government and individual business owners will directly apply those characteristics which lead to a productive outcome. According to [5], Firm's

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characteristics include the growth strategies for management personnel and the entire firm. Firm's characteristics determinants have the greatest influence on the growth of a firm. These strategies regarding the features of the firm such as ownership type, size, age, human capital possibly affect the growth pattern of the firm. The correlation of age, size and growth is major recognised issues in the literature under the Law of proportionate effect also known as the Gibrat's Law, [6] which was formulated by Robert Gibrat in as early as 1931 [7]. Likewise, other explored influential factors via literature on firm's characteristics such as the high desire of the firm to grow, high-level of human capital, a clear mission and clear vision of business also impacts on firm's growth. Additionally, good management structures, good team, good human relations, high-level of knowledge of the team, positive culture and good location of the firm also contribute the growth of the firm.

2. The purpose of the study

This study aims to fill the gap in the characteristics of a firm as a contribution to firm's growth. Further, the study explored the determinants of firm's characteristics in enhancing an integrated growth in a firm.

3. Literature and Hypotheses

3.1. Firm's relationship with age and growth

The growth of firms depends primarily on the momentous characteristics of the firm which may be categorised as tangible or intangible.Tangible growth includes an increase in size of employees, stock, turnover and no sub-firms while intangible growth comprises a brand name, firm's prestige such as goodwill [8]. Literature, particularly on the Law of proportionate effect which was formulated by Gibrat in as early as 1931 stressed on the influence of firm's age and size on growth intangible. Although the Gibrat's Law was established, in theory gives clear guidance on how firm's age control firm's growth [9]. A study by [10] discovered that young firms within a sector are likely to face the liability of newness, while the older firms may have a better understanding of the firm's niche environment and be expected to have smooth growth with few rocky paths [11]. [12] supported that firm's age is a significant influence on the firm growth of, with younger companies growing faster than old firms. This implies that the relationship between firm's age and growth within a sector is particularly vigorous. Conversely, studies in both developed and developing economies shown, that young SMEs have more prospects to have high rates of growth compared with SMEs that have been in existence longer [13]. [14] on the other hand stressed that the average growth rate of firms decreases with age. This, therefore implies that the older a firm, the lesser growth ensue within the firm. According to [15] firm owners stressed that their efficiency increases with time and the age of their operations. [9] similarly argued that films initially expand and then taper-off its growth as the firm approaches its optimal size. In practicality, firms may benefit from its age regarding learning by doing which brings about increase in explicit expertise and entire growth. On the other hand, firm's suffer productivity losses as they age [16]. It can, therefore, be concluded that firm's age has a relationship with its growth.

3.2. The high desire of the firm to grow

The high desire of the firm to grow is an impetus to firm characteristics which results in growth. The firm's zeal to growth is vital to enable a collaborative desire among management team that is the bedrock of policy formulation. [17] pointed that studies have established that growth desires are positively related to actual growth. This implies that, higher growth desires of a firm encourage realisation of actual growth. According to the resource-based view of the firm, resources are the primary source of firm's performance and shows the direction for firm's strategy as its characteristics. Further, [18] remarked attitudes to growth depend on the expected consequence of growth. [18] also supported that, growth desires of a firm is hinged on the owner type, the entrepreneurial abilities of the management team and the organisational driven policies.

3.3 High-level of human capital

Every firm is characterised by its level of human capital or resource. The higher the level of human resource of a firm, the likelihood of achieving higher productivity and precision. [19]asserted that people are the key source of firm's competitive advantage. Therefore, the level of human capital within a firm impacts on the growth of the firm. Furthermore, it is the quality of the human resource that determines organisational performance and level of productivity. A firm characterised by a high human capital would possibly attain higher products under reliable supervision

3.4 Clear mission and clear vision

A firm with a clear mission and vision is expected to achieve its goals extensively. [20] hypothesised that a firm could not have values beliefs and purposes outside the people who make up that business. Therefore, it is important that the firm establishes a clear mission and vision comprehensible to all its employees to drive the firm towards its growth. [20] further stressed that mission statements serve to inform not only employees but also the outside world such as stakeholders, neighbours among others about the important functionalities of the firm. Further, it also severs as anchors and guidepost for both strategic and operational decisions making to facilitate growth. This suggests that clear mission and vision as a characteristic of a firm drives growth to be achieved. [21] on the other hand supported that for firms to grow, the entrepreneur needs to formulate an accurate, clear vision for the firm.

3.5 Good management structures

Establishing proper management structure ensures an organisation's continued growth, content employees and profitable returns for shareholders of the company [22]. Consequently, a wrong management structure creates tension between workers and managers, allows inefficient work practices to flourish and reduces company's profitability thereby affecting growth with a further consequent of firm's closure. A good management structure in a group has the following key components underpinning the structure. These include effective communication style, proper task definition, formalisation of procedures, good relations and customers [22]. [23] supported that, good management structure in a firm is essential in defining individual responsibilities within the minimum resistance resulting in significant corporate productivity and growth.

3.6 Good team, good human relations

According to [24], several studies have suggested that firms founded and managed by good teams are more successful than firms established and led by a single person. Further, firms with diverse teams of a range of management skills and competencies have greater opportunities of surviving thereby resulting in the growth of the business. Also, a firm is characterised by the good team operating within with the aim of accomplishing targets that individuals cannot achieve working alone. The human relation is the skill or the ability to work efficiently through and with others [25]. Therefore, when a good human relationship describes a firm, it drives goals and growth to be achieved. A good human relationship in a firm however, includes a desire to understand others, their needs, weakness talents and abilities. Moreover, good human relationship within a firm foster conducive working atmosphere that further yields more productivity and bring about firm's growth. Undoubtedly, uniqueness in the knowledge of a good team within the firm results in distinct output and performance which impacts on the company's growth [26] affirmed that effective team and knowledge is appreciated as one of the few broad-spectrum of success factors firm's growth.

3.7 Positive culture

Every firm has its culture. According to [27], the culture of a company can be by default or by design. If the firm's culture is by default them, it means a chance of the company growing healthy is not enhance since most team members are not engaged. However, a firm with design culture constitutes the one with leadership instituting and developing engagement of employees [27]. Therefore, when a firm is characterised by design culture, it is associated with extensive outputs which result in growth.

3.8 Good location of the firm

Location of a firm as its characteristics impacts on the firm's growth and performance through positive and negative externalities [28]. Further, there is a likelihood of a positive effect of a company in a small geographical area regarding their levels of efficiency. For instance, research conducted by [29] maintained that company's location and its operation is primarily influenced by the desired growth of the firm which comes about because of the economic, demographic, environmental and social factors surrounding the firm.

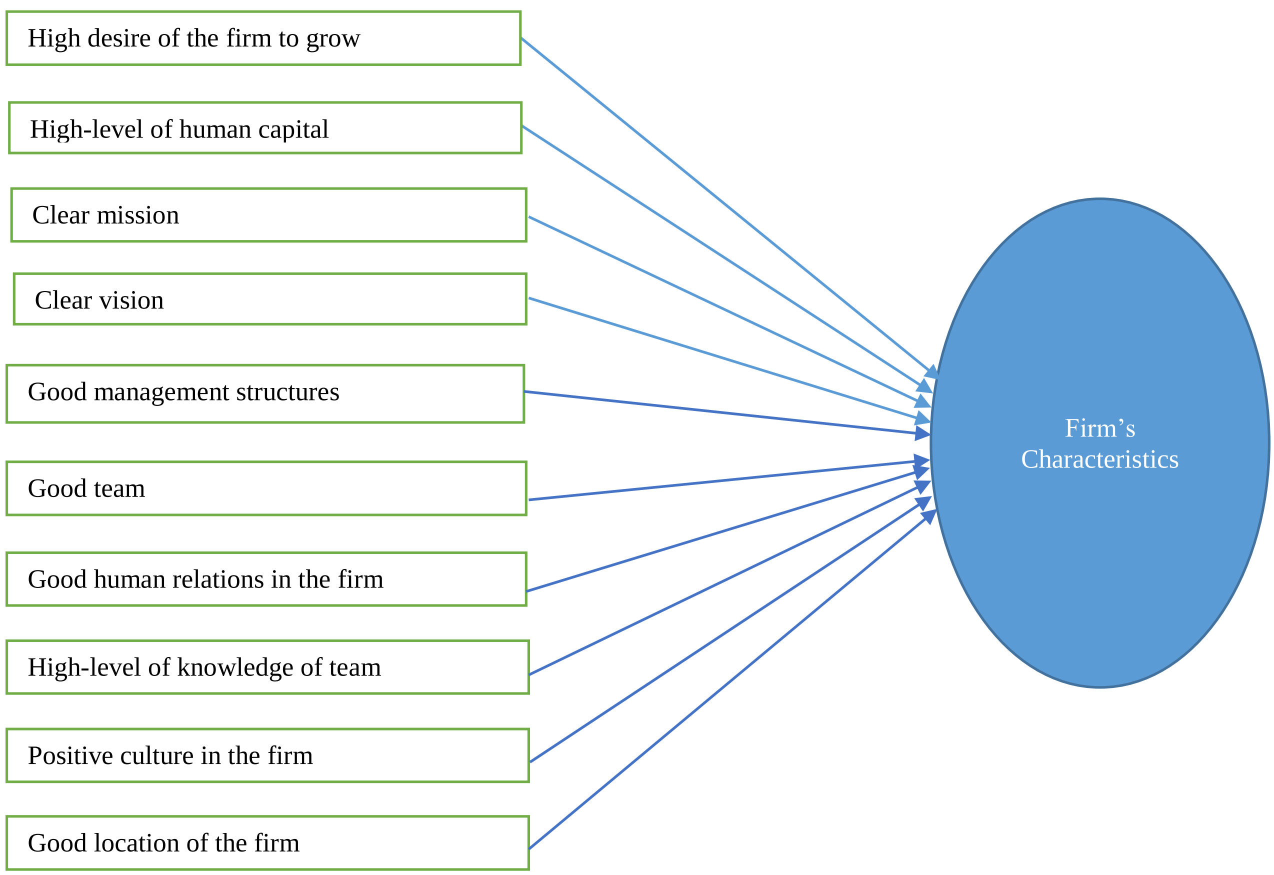

Figure 1: Conceptual framework
Source: Adapted from Arthur-Aidoo (2017)

4. Dependent variable

The dependent variable is firm's characteristics. As depicted on figure 1. This variable (firm's characteristics) can be measured can however be measured by some attributes such as the high desire of the firm to grow, high-level of human capital, a clear mission and clear vision of business also impacts on firm's growth. Additionally, good management structures, good team, good human relations, high-level of knowledge of the team, positive culture and good location of the firm [30]. Accordingly, sound firm's characteristics also contribute to the growth of the firm.

5. Independent variables

The independent variables include high desire of the firm to grow, high-level of human capital, a clear mission, clear vision of business, good management structures, good team, good human relations, high-level of knowledge of the team, positive culture and good location of the firm [30].

6. Methodology

This research is partly exploratory supported by questionnaire survey. To ascertain the reliability of the collated data, both review of literature augmented by questionnaire survey was adopted. Extensive review of literature using current peered reviewed journal and conference publications were used. Further, primary data through the used of the questionnaire assisted in gathering relevant information from 20 sampled small and medium-sized construction firms randomly selected through the list of SMEs operating within the Greater region of Accra in Ghana and its sub-metropolis. Data were analysed with the aid of statistical package for social sciences (SPSS) version 24 using exploratory factor analysis technique. The study used independent variables which measured and brings about sound firm's characteristics thereby encouraging entire growth. This provided an opportunity to evaluate the importance of the independent variables as causal determinants of firm' characteristics for growth.

7. Discussion

In this study, exploration was done to establish the determinants of firm's characteristics which further brings growth in a firm. Discussion of the study was based upon review of the literature, summary of the factors classified as independent variables and the collated data from the questionnaire survey which measured firm characteristics. These 10 factors (FCS1, FCS2, FCS3, FCS4, FCS5, FCS6, FCS7, FCS8, FCS9, and FCS10) which influenced firm characteristic (FCS) were subjected to factor analytical test (EFA), only 3 questions were found suitable and were extracted. The Kaizer Meyer-Olkin (KMO) test generated 0.800 which indicate higher adequacy of the sample. According to [31], the Kaizer Meyer-Olkin (KMO) measure of sampling adequacy of 0.5 is considered adequate and supports the adequacy of the sample size for the factor analysis in this current study. A KMO value of 0.5 ideally is recommended in literature for sample size adequacy and to justify the used of factor analysis in the present study supported by the appropriateness of the factor for the model [31]. Moreover, the exploratory factor analysis shown the result of Bartlett's test of Sphericity of 746.111 with an associated significance level of 0.00 presented in Table 1**.** The implication of this result is that potential correlation exists between the variables and hence revealing of a realistic group forming factors from the variables [32]. Likewise, the Cronbach's alpha of 0.798 was established indicating a satisfactory level of internal consistency and reliability in the measures and scale [31]. [32] pointed that a Cronbach alpha value of 0.7 is considered reasonably good measuring scale for internal consistency and reliability of a research instrument. Communalities extracted on individual variable were assessed before the analysis shown in Table 2. These commonalities were significant in determining the variables that have been extracted [32]. This also means that the communalities epitomize the total amount of variables captured under firm characteristics in the factor analysis. Also, an acceptable rule for communality values in factor analysis suggests that a potentially significant variable must produce an eigenvalue (extraction value) in the iteration. From Table 2, the average communality after extraction was 0.60; this was in conformity of [32] which stressed that the average communality must be above 0.60 after extraction to support the reliability of analysis. [31] emphasised that eigenvalues of less than one are considered insignificant, these were excluded accordingly in the current study from Table 3. From the results shown in Table 3, seven variables had their enginevalues less the cut-off point of 1. This indicates that the variables do not describe much variance and were, as a result, dropped from the analysis as suggested by [32]. Similarly, the pattern matrix in Table 2 shows the three factors that dominated and belonged to the unique factor component. Furthermore, it could be emphasised that these three factors that emerged in the iteration could be perceived as the dominant factors accentuating firm characteristics for integrated growth of construction SMEs.

TABLE 1: FIRM CHARACTERISTICS (FCS)

KMO and Bartlett's Test[a]		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.800
Bartlett's Test of Sphericity	Approx. Chi-Square	746.111
	Df	45
	Sig.	0.000

a. Based on correlations b. Cronbach's Alpha = 0.798

TABLE 2: PATTERN MATRIX[A]

Pattern Matrix[a]				
	Code	Component		
Firm Characteristics (Variables)		1	3	4
Clear vision	**FCS4**	0.914		
Clear mission	**FCS3**	0.835		
High desire of firm to grow	**FCS1**	0.736		
High level of human capital	**FCS2**	0.603		-0.238
Good location	**FCS10**		0.899	-0.231
Positive culture in firm	**FCS9**		0.690	-0.209
Good human relations in firm	**FCS7**			-0.749
Good team	**FCS6**			-0.749
High level of knowledge	**FCS8**		0.230	-0.712
Good management team	**FCS5**	0.327		-0.498

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

TABLE 3: TOTAL VARIANCE EXPLAINED

Total Variance Explained							
	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	3.980	39.795	39.795	3.980	39.795	39.795	3.292
2	1.273	12.734	52.529	1.273	12.734	52.529	1.736
3	1.096	10.965	63.494	1.096	10.965	63.494	2.854
4	.864	8.644	72.138				
5	.742	7.418	79.556				
6	.568	5.680	85.236				
7	.463	4.629	89.865				
8	.402	4.022	93.887				
9	.318	3.177	97.064				
10	.294	2.936	100.000				

Extraction Method: Principal Component Analysis.
a. When components are correlated, sums of squared loadings cannot be added to obtain a total variance.

8. Conclusions

The study aimed to fill the gaps in firm characteristics and their determinants which contributes to firm's growth. Accordingly, the study explored these determinants and further depicted the conceptual ideal in a model form. The study concludes that the roles of SMEs in any economy are not limited to solely the provision of employment, facilitation of socio-economic infrastructural needs and poverty reduction but also the growth of the firm. Growth among SMEs varies from nations and among industries and may be measured in several levels including sales employees growth over a particular period. In view of that, comprehending firm's growth has become an essential concern for researchers and policymakers. Therefore identifying the channel that promotes small and medium-sized firm's growth that will provide the basis to influence strategic direction to create the environment and the required initiatives to help other informal sectors is crucial. Despite the established numerous of determinants of firm's growth among SMEs, there is still a dearth of firm's characteristics as a determinant of firm's growth among construction SMEs which influence growth. The study concludes that the explored influential factors via literature on firm's characteristics such as the high desire of the firm to grow, high-level of human capital, a clear mission and clear vision of business also impact on firm's growth. Additionally, good management structures, good team, good human relations, high-level of knowledge of the team, positive culture and good location of the firm also contribute the growth of the firm. The study conceptualised the dependent variable as firm's characteristics and was measured by independent attributes such as the high desire of the firm to grow, high-level of human capital, a clear mission and clear vision of business also impacts on firm's growth. Additionally, good management structures, good team, good human relations, high-level of knowledge of the team, positive culture and good location of the firm also measured the dependent variable. The study also generated a Kaizer Meyer-Olkin (KMO) test value of 0.800 which indicated a higher adequacy of the sample and also supports the sample size for the factor analysis in this current study. Similarly, the Cronbach's alpha of 0.798 from the study was established indicating a satisfactory level of internal consistency and reliability in the measures and scale.

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Fuzzy Logic Model for Initial Project Screening with Consideration of Decision Position

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Abstract

In planning for a construction project, the owner often has several alternatives regarding the site or the building that are available for selection. Evaluation of the project alternatives and then ranking them in preference so as to select the overall best one for implementation is the key issue that influences project success. This paper proposes a model for initial screening of project alternatives with consideration of the owner's decision position that is reflected by the priority differences between the decision factors. The model uses the fuzzy inference system to perform mapping from the estimates of the factors or the inputs for an alternative to its score or the output. In order to illustrate the model, hypothetical alternative sites of a housing project for a developer firm are assumed and an example fuzzy inference system is built to simulate evaluation and ranking of them. First, three variables, i.e. project size, project conditions, and unit development cost, are used as the input variables that determine the desirability of a site in initial project screening. Next, the linguistics values of the input and output variables each are defined with a set of membership functions. Then, the fuzzy rules that represent the owner's decision position in a possible scenario are set up. For given inputs, the output is produced by mathematical operations on the rules. The assessments and rankings obtained are found to be consistent with the inputs for the sites and the decision position, showing that the model can capture the effect of nonlinear input-output relations and is potentially useful for initial project screening.

Keywords: decision position; evaluation; fuzzy logic; housing development.

1. Introduction

In planning for a construction project, whether in the public or private sector, the owner often has several alternatives that are available for selection; for example, a few sites available for development and at a site different types of building available for erection. Performing analysis of the alternatives and ranking them so as to select the overall best one for implementation is the key issue that influences success of the project. There have been many cases of project failures due to improper project selection, resulting in wastes of valuable resources. The existing methods for project assessment, such as the net present worth method, the utility theory method, and the analytic hierarchy process method, each have some disadvantages.

The traditional net present worth (NPW) method is based on the estimated cash flows of incomes and expenses for the alternatives, but it is difficult to include intangible benefits and risk factors and so the result may not represent their overall values. The utility theory method, which is multi-attribute decision analysis (MADA), can include quantitative and qualitative elements as evaluation criteria and produces a total utility score for each alternative [1,2]. However, it has difficulty in determining criteria weights and utility functions. The analytic hierarchy/network process (AHP/ANP) method structures the evaluation as a hierarchy/network to contain all criteria and uses paired comparisons to generate criteria weights and then aggregates the alternatives' overall scores [3,4]. However, the

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AHP/ANP method has no explicit functions in producing ratings and so lacks transparency. To redress the above shortcomings of the existing methods is the motivation for the present research.

The objective of this research is to develop an improved model for assessing and ranking alternatives in initial project screening. For the purpose of initial project screening before a final selection is made, the model should be able to differentiate the more favorable ones from the less favorable ones. Therefore, the model needs to include only the main factors, both quantitative and qualitative. Moreover, the model needs to address the decision position of the project owner that is reflected by the priority differences between the factors.

2. Research method

It is proposed to use fuzzy logic (also called fuzzy inference) for mapping of the output (score) for an alternative from the inputs (factors) for it, because project assessment involves great complexities and fuzzy logic can deal with complex nonlinear input-output relations. Fuzzy logic has found applications in many areas of construction [5,6,7]. It is based on the concept of fuzzy sets or membership functions for describing the values of linguistic variables. Fuzzy rules in the form of IF *preconditions* THEN *consequences* are employed to emulate the linguistic way that humans judge in dealing with different circumstances. An inference is achieved by mathematical operations on the rules to determine the output for given inputs. Steps of the inference process include fuzzifying crisp inputs, calculating rules' firing strengths, weighing consequences, aggregating weighed consequences, and defuzzifying the result into crisp outputs. Through the collective effect of the fuzzy rules on the output for given inputs, fuzzy logic can accommodate imprecise data and achieve robustness. The strength of the fuzzy logic is to produce consistent results, while keeping to tractability [8].

Selection of alternative sites by a developer for housing development is used herein as an example to illustrate the proposed model for initial screening of project alternatives. From a previous study [4], three important factors that influence a site's overall strength are identified as the criteria for evaluating alternative sites. The first factor is project size, which refers to the gross floor area as planned for a site according to its acreage and land use regulations. The second factor is project conditions, which are defined by three sub-factors. The first sub-factor is surroundings conditions, which refer to a site's external environments including completeness of transport systems, access to public transports, availability of public facilities such as schools, markets, and services, and distance to unfavorable places such as cemetery and landfills. The second sub-factor is plot use and construction plan, which refer to a site's suitability for housing development and construction concerning the plot shape, terrain, and ground conditions. The third sub-factor is local demand and competitiveness, which refer to the expected demand and competition for sales of new housing in the local area. The last and third factor is total development cost, which refers to all expenses needed in the project as planned for a site and comprises purchase of the site, planning and design, construction, management and marketing.

In the present study, hypothetical alternative sites for a housing development project in Kaohsiung, Taiwan are assumed for a developer and used for illustrating the proposed fuzzy logic model by simulation of assessment and ranking of them in priority. The framework of the model for initial screening of alternative sites for a housing project is presented in the following section.

3. Description of model

For an overall assessment of alternative sites for housing development, the three factors mentioned above, i.e. project size, project conditions, and unit development cost, are used as the input variables for building the proposed evaluation model. Project size is defined as the planned gross floor (m^2) for a site. Project conditions are a qualitative factor and assessed on a scale of 0-100 measuring the degree of favorableness of a site by considering surroundings conditions, plot use and construction plan, and local demand and competitiveness together. Unit development cost (NT$/$m^2$, 1NT$≒0.03US$) is defined as the estimated total development cost divided by the planned gross floor area for a site. The output variable of the model is the score assessed for a site on a scale of 0-1. See Fig. 1 for the input and output variables of the model.

In fact, there are two inferences involved in the model. The first inference is to assess the project conditions of a site based on the site's ratings of surroundings conditions, plot use and construction plan, and local demand and competitiveness. The second inference is to produce the overall assessment of a site based on the site's project size, project conditions assessment, and unit development cost. However, for the sake of simplicity, only the second

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inference is presented in the example herein, while the result of the first inference for a site is assumed as a 0-100 rating.

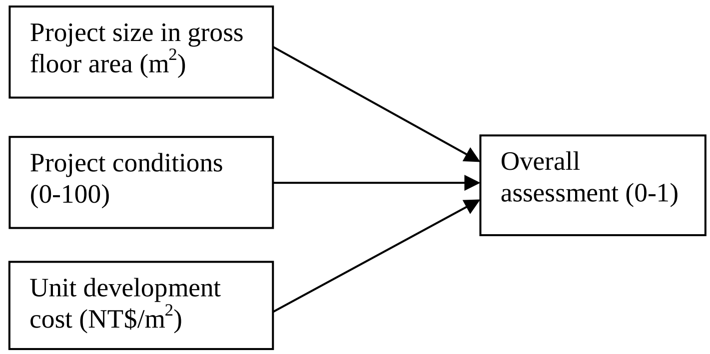


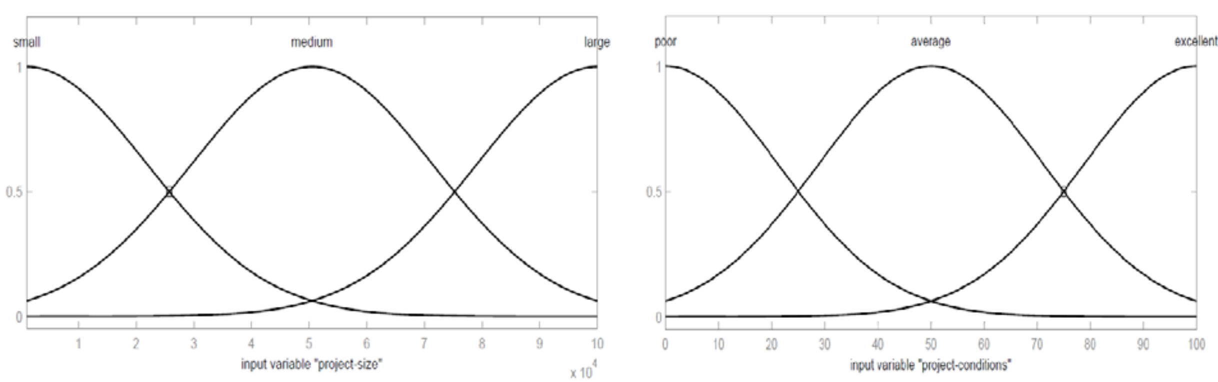
Fig. 1. Inputs and output of model for evaluating alternative sites.

The membership functions, fuzzy rules, and mathematical operations used in the inference for overall assessment are explained below. The linguistic values or levels of each input and output variable in the fuzzy rules are defined with a set of membership functions separately. It is proposed to use the Gaussian membership function to describe the levels of each input variable, which are the preconditions of the rules. The range of value of an input variable or the domain of the membership functions is set based on the possible project cases for a developer. The parameters of a membership function are set so that the adjacent curves intersect at membership of 0.5 and the overlapping can cause the consequences of quite a few rules to impact the output collectively. The Gaussian membership function is defined in (1) below:

$$m = f(x, \sigma, c) = e^{\frac{-(x-c)^2}{2\sigma^2}} \quad (1)$$

where x = value of an element in the domain of function f ; m = value of membership function f at x in f; c = position of the center of the peak; σ = standard deviation.

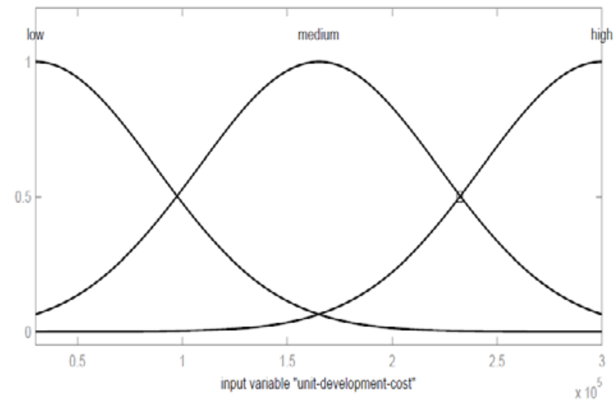
Assuming that project size's range is 1,000~100,000 m^2, the three membership functions in Figure 2(a) are used to define the three linguistics values, where σ = 21000, c = 1000 (small), 50500 (medium), or 100000 (large). As project conditions are assessed on a scale of 0-100, the three membership functions in Figure 2(b) are used for the variable, where σ = 21.25, c = 0 (poor), 50 (average), or 100 (excellent).



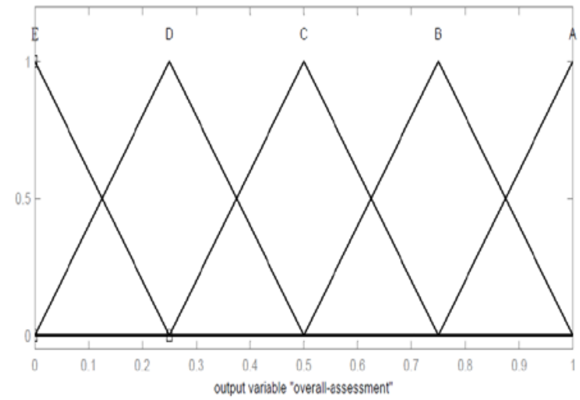
(a) (b)

Fig. 2. Membership functions for fuzzy variables (a) "project size" (b) "project conditions".

Assuming that unit development cost's range is 30,000~300,000NT$/m^2, the three membership functions in Figure 3(a) are used for the variable, where σ = 57500, c = 30000 (low), 165000 (medium), or 300000 (high). It is proposed to use the triangular membership function to describe the levels or ranks of the output variable "overall assessment", which are the consequences of the rules. As the score of a site is assessed on a scale of 0-1, the three membership functions in Figure 3(b) are used for the variable, where base width = 0.5, center = 0 (E), 0.25 (D), 0.5 (C), 0.75 (B) or 1 (A).



(a)



(b)

Fig. 3. Membership functions for fuzzy variables (a) "unit development cost" (b) "overall assessment".

Addressing the developer's decision position in a possible scenario, the set of fuzzy rules that reflect the decision position by the priority differences between the input variables are set up for producing a score for given inputs of the project size, project conditions assessment, and unit development cost for an alternative site. The preconditions of each rule consist of the linguistic values of the input variables, i.e. a level of project size (small, medium, or large), a level of project conditions assessment (poor, average, or excellent), and a level of unit development cost (low, medium, or high). The connection between the preconditions can be the "AND" operator or the "OR" operator, while some preconditions in a rule may be absent. The consequence part of each rule is a rank from "A" to "E" assigned for the preconditions.

The reality of housing development is that a site with better project conditions has a greater potential for sales but also requires a higher development cost because of a higher land price and causes more concern. Although a site with poorer project conditions has a less potential for sales, it requires a lower development cost because of a lower land price and causes less concern. Whether the priority is project conditions or unit development cost or the two factors are equally important depends on decision position, which is reflected by a set of fuzzy rules. Besides, the optimal project size depends also on decision position; it is not necessary that the larger the better because of the concern about the higher financial risk due to greater possibility of more unsold units for a greater project size. Assume a scenario of the developer pursuing higher sales brought by better project conditions of a site but also having an aversion to greater concern caused by higher unit development cost, meanwhile considering medium project size best, followed by small project size and large project size. Then, a set of fuzzy rules suitable for the decision position are set up as shown in Table 1.

Table 1. Example fuzzy rules for evaluating alternative sites

Project size	Project conditions	Unit development cost	Rank
Medium	Excellent	Low	A
Medium	Average	Medium	B
Medium	Poor	High	C
Small	Excellent	Low	B
Small	Average	Medium	C
Small	Poor	High	D
Large	Excellent	Low	C
Large	Average	Medium	D
Large	Poor	High	E

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In Table 1, the first rule reads "for a alternative site being assessed, if the project size is medium, and the project conditions are excellent or the unit development cost is low, then its rank is A." It has the effect of two rules: "if the project size is medium and the project conditions are excellent, then the rank is A" and "if the project size is medium and the unit cost development cost is low, then the rank is A." Therefore, the rank A is assigned to a site that meets the preconditions of any one of the two rules. The remaining eight rules have similar effects. These rules indicate that the assigned rank generally turns worse following the order of medium, small, large project size and within each level of project size the rank turns worse with poorer project conditions or higher unit development cost. For this decision position, the site with the highest score obtained from the fuzzy inference is likely the one with all inputs close to the middles, representing a compromise.

A set of fuzzy rules, the membership functions for the rules, as well as the mathematical operations used in fuzzy inference comprise a fuzzy inference system (FIS). In the illustrative example FIS, the process of transforming the inputs for an alternative site to the output (score) for it is explained in the steps below.

1. Let the memberships of k inputs in the preconditions of rule i be $m_1, m_2,\ldots, m_k$, respectively, then either (2) or (3) below is used to calculate the firing strength of rule i (F_i).

   For the "AND" connection between the preconditions of rule i,
   $$F_i = \min(m_1, m_2, \ldots, m_k) \quad (2)$$
   where operation min stands for minimization.

   For the "OR" connection between the preconditions of rule i,
   $$F_i = \max(m_1, m_2, \ldots, m_k) \quad (3)$$
   where operation max stands for maximization.

2. The obtained firing strength F_i from step 1 is used to weigh the consequence membership function of rule i, $m_{ri}(x)$, which is the rank assigned. The step is called implication and the result of it is:
   $$s_i(x)= \min(F_i, m_{ri}(x)) \quad (4)$$

3. By aggregating the weighed consequences of all n rules, the obtained overall results is:
   $$S(x) = \max(s_1(x), s_2(x), \ldots, s_n(x)) \quad (5)$$

4. The final step is to defuzzify the result of step 3 by calculating the x value of the centroid or the center of the area defined by $S(x)$, which is very likely a polygon, to produce the score of the site, and the score is a value between 0 and 1.

For building the fuzzy inference system above, MATLAB's Fuzzy Logic Toolbox (MATLAB, 2014) can be used because its graphical user interfaces facilitates formulation and revision in model development. Sets of fuzzy rules for overall assessment of alternative sites in other scenarios and those for project conditions assessment from its sub-factors can be set-up similarly according to corresponding decision positions. When the model is put to use, the estimates of the input variables for each alternative site are made and entered into respective FIS to produce the overall assessments of the alternative sites as the outputs for a decision position.

4. Example site assessment and results

It is assumed that a developer with a modest financial capacity in planning a housing development project has five hypothetical alternative sites, A, B, C, D, and E available for selection. The proposed fuzzy logic model is used for simulation of assessment and ranking of the sites in initial project screening. The values of the input variables shown in Table 2, i.e. project size, project conditions, and unit developments cost for each site, are entered into the above FIS to produce the scores of the sites. The results are also shown in Table 2; site C with the highest score ranks first, followed by site A and site B, while site E and site D rank lower. The rankings obtained are consistent with the site' strengths and weaknesses from the viewpoint of the decision position or the priority differences between the factors as reflected by the fuzzy rules in Table 1; project size is the most important factor, while project conditions and unit development cost are equally and less important factors. In comparison with other MADA methods, the fuzzy logic model has an important advantage for the example: it would be difficult to use utility functions in the form of a smooth curve to achieve the effect of order of preference for project size: medium first, small next, and large last, while using AHP/ANP still have the problem of lacking transparency in the ratings entered.

Table 2. Project size, project conditions, unit development cost, and score of the alternative sites in the illustrative example

Alternative site	Project size (m^2)	Project conditions (0-100)	Unit development cost (NT$/$m^2$)	Score (0-1)
Site A	60,000	70	160,000	0.649
Site B	30,000	85	200,000	0.618
Site C	45,000	60	120,000	0.708
Site D	75,000	45	80,000	0.534
Site E	70,000	55	85,000	0.589

5. Conclusions

Initial project screening is important for construction owners since it influences the final outcome of a project. A fuzzy logic model is proposed in the paper for assessment and ranking of alternative sites for a housing development project. The model comprises membership functions for the input and output variables, fuzzy rules incorporating decision position by reflecting the priority differences between the input variables, and mathematical operations for processing inputs and producing the output. The model is illustrated with an example, in which project size, project conditions, and unit development cost are used as input variables and five sites are assessed. The results obtained are consistent with the sites' strengths and weaknesses from the viewpoint of a possible decision position. As compared to other methods, the model can better capture non-linear effects of the decision position. It is emphasized that the result from the model can only be considered as suggestion of initial screening, and so more in-depth study of those accepted in the screening should be done in order to determine the final selection with other decision factors not included in the model.

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Generating a visual map of the crane workspace using top-view cameras for assisting operation

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Abstract

All terrain cranes often work in construction sites. Blind spots, limited information and high mental workload are problems encountered by crane operators. A top-view camera mounted on the boom head offers a valuable perspective on the workspace that can help eliminate blind spots and provide the basis for assisting operation. In this study, a visual 2D map of a crane workspace is generated from images captured by a top-view camera. Various types of information can be overlaid on this visual to assist the operator, such as recording the operation and projecting the boom head's expected path through the workspace. Herein, the process of generating a visual map by stitching and locating the boom head trajectory in that visual map is described. Preliminary proof-of-concept tests show that a precise map and projected trajectories can be generated via image-processing techniques that discriminate foreground objects from the scene below the crane. These results show a way to help the operator make more precise operation easily and reduce the operator's mental workload.

Keywords: all-terrain crane, top-view camera, optical flow, image stitching;

1. Introduction

All-terrain cranes are widely used in construction, transportation and other industries due to their good mobility and capacity [1]. Fig. 1 shows an all-terrain crane in operation. A load is suspended from the boom and transported.

The operators of all-terrain cranes face a constantly changing workspace. The chief dangers to crane operators are a congested working environment, neglect of hidden dangers, and a lack of information for decision making especially for the operators with little working experience. Oscillation of the suspended load can also present a challenge to crane operators. Many studies have addressed methods for reducing oscillation with the control theory for more precise lifting [2-4] and have mostly focused on structural features of the crane itself. Lifting path planning is also a promising way to improve the precision and efficiency of crane operation [5]. Safety and precision can be improved with a careful consideration of the workspace. Thus, accurate 3D information about the environment is required. Precise scanning of the environment and data processing

Fig.1 A crane in operation. A load is suspended to the boom and transported. A top view camera is also suspended at the top of the boom to survey the working environment.

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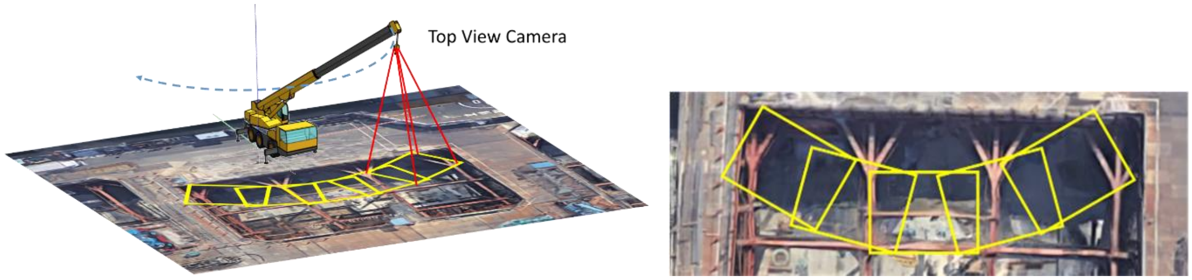


(a) Top-view camera surveying workspace (b) Stitching to generate a workspace map

Fig. 2. (a) A top view camera suspended from the boom head continuously capturing images shown in yellow rectangles of the workspace. (b) Image-stitching process to stitch these images to produce a wide-range image of the workspace.

tend to be time consuming and cost a lot. One lab, for example used data from crane sensors to roughly examine the working environment for path planning [5].

In this study, the crane operator's limited visibility and insufficient information about the workspace are the primary concerns. As shown in Fig. 2. (a), a top-view camera is mounted on the boom head that moves over the workspace along with the boom. Bird's-eye view images can be captured using the top-view camera. With several images captured from the top-view camera, a wide range of the workspace can be represented by stitching and rendering these images, as shown in Fig. 2. (b). The stitched top-view camera image can provide a rich range of information to the operator. Herein, the stitched wide-range image is referred to as the workspace map. A variety of assistance applications of the workspace map can be considered. An optimal path to transfer a load can be displayed on the workspace map to aid the operator. Information, such as the position of the boom head and a 2D projection of the lifting path, can also be included in the workspace map, along with other representations that researchers may devise in the future.

2. Foreground detection and mask generation

To generate a clear overall workspace map, the workspace must be imaged beforehand. This pre-shooting process requires the following conditions, which are diagrammed in Fig. 3.

- The top-view camera is located at the top of the boom at a sufficient height to cover a wide area of the workspace.
- The optical axis of camera should be pointed vertically at the ground.
- While taking the images, the top-view camera rotates with the boom's rotation only. If an extension of the boom is necessary, the height of the top-view camera should be kept as constant as possible to make images captured having a close scale.
- Images captured with the top-view camera include background and foreground objects. The background is the ground and objects resting on it. The foreground includes objects that are hung to the boom and move along with it, such as a hook, a wire, and a swinging load. During the pre-shooting process, the foreground should be removed as much as possible as they must not show up in the workspace map as ghosts. For this reason, during the pre-shooting, winding up the cable and detaching the load are recommended. But it is impossible to exclude them completely. We need some means to detect the foreground.

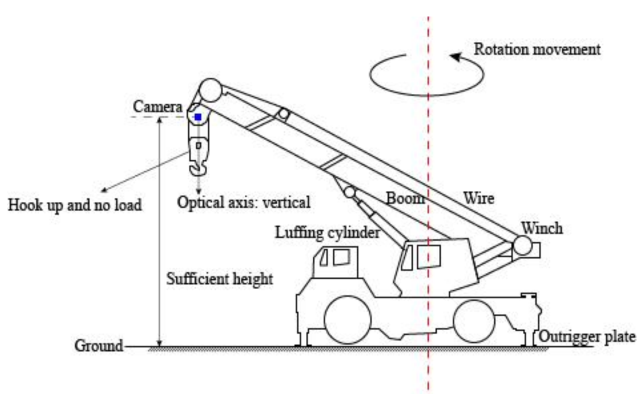
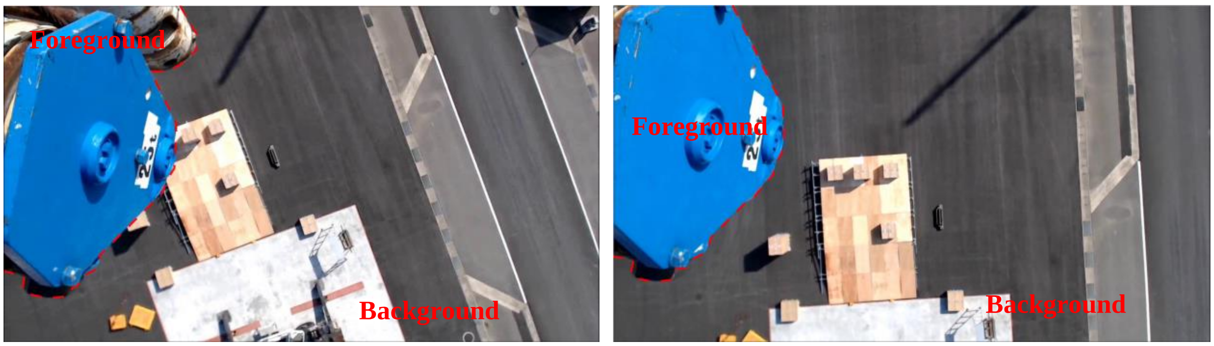


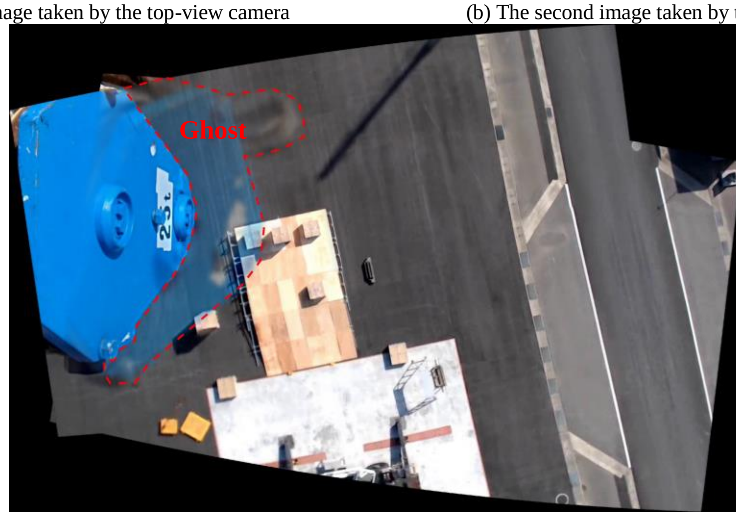
Fig. 3. Conditions of pre-shooting of the background images

Under these assumptions, the images captured with the top-view camera can be composed using panoramic stitching [6]. Fig. 4 shows typical images captured by the top-view camera under the conditions mentioned above. These images are stitched together to generate a workspace map that covers the whole background over which the crane has gone through. However, even under the conditions mentioned above, these images still often contain such foreground objects as a boom head and a hook. Simply stitching these images will cause ghosts of these foreground objects to appear in the final stitched workspace map. For example, in Fig. 4., stitching the workspace map directly from images (a) and (b) captured by the top-view camera yields a ghost in the resulting image (c).

To generate a clean workspace map, it is better to generate a mask to eliminate the foreground objects and prevent ghosts appearing in the reference map.



(a) The first image taken by the top-view camera (b) The second image taken by the-top view camera



(c) Stitching result

Fig. 4. (a)(b) Typical top view camera images contain foreground object (a hook) enclosed with dotted red lines the background. (c) Stitched image directly using images (a) and (b) has ghost of the hook in the region enclosed by red lines.

2.1. Motion segmentation with moving camera

We should remove the foreground objects by masking them with a mask covering them precisely. It is necessary to discriminate the background and foreground objects in the images. One method to distinguish them is by the difference of their motion. This problem is known as motion segmentation with a moving camera [7].

Serajeh has proposed a method for this problem based on epipolar geometry and dense optical flow [8]. That method is intended to extract moving objects from images captured with a hand-held moving camera. This paper considers the addressing of this problem using such a structure from motion (SFM) technique. First, with RANSAC algorithm, the epipolar geometry between two images is estimated to calculate the fundamental matrix. Second, the dense optical flow is calculated to find the corresponding point in the second image for every pixel in the first image. Then the corresponding points in the second image that keep a significant distance to the epipolar lines are detected as moving objects in the scene. This process is applicable to a wide range of cases.

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Under some conditions, however, the SFM technique will not yield satisfactory results. One extreme condition is if the image planes of two camera position while capturing is parallel to each other. The epipolar lines on both images will be parallel. If the foreground objects are moving on these epipolar lines, all the foreground objects will be on epipolar lines, making the measurement of epipolar distances impossible. This extreme condition happens rarely because it requires the two image planes parallel to each other and the foreground objects moving on the epipolar lines. Another example is that in which the movement of a moving object is complicated with both translational and rotational movements. In this case, some points on the moving object may lie on epipolar lines of the second image while the rest do not. Then, part of the moving objects can be detected in the first image. Unfortunately, this condition always happens for the images captured by the top-view camera of crane.

2.2. Proposed method

From one image to another image captured with the top-view camera, foreground objects will always show a complicated movement because of the crane hook's oscillation. Because of this complicated movement, only parts of the foreground object will lie on epipolar lines from the perspective of the second image, so the foreground cannot be detected in full.

One of this article's main contributions is to make up for this shortcoming in epipolar geometry by separating foreground and background objects based on a combination of dense optical flow and homography. This method computes the relatively subtle trajectory of the background as represented in homography and compares that motion with the dense optical flow between the images.

Homography represents a linear transformation between two images. The optical flow of the background should be consistent with the homography. However, the optical flow of foreground objects will not be consistent with the homography between the images.

To illustrate the difference of foreground and background optical flows' matching with homography, a simple diagram of the proposed method appears in Fig. 5(a). Both optical flow and homography are representations of pixels' movement from one image to another. In Fig. 5(a), optical flow is represented as the movement from red points to blue points. And homography is the movement from red points to green points. For background, the movements of red points to blue points and red points to green points are the same, i.e., the optical flow is consistent with the homography. However, for the foreground, movements of red points to blue points and red points to green points are not the same, i.e., the optical flow is not consistent with the homography. If and only if pixels of the foreground have the same movement with the background, detection of these pixels will fail.

Fig. 5. (b) shows a test on images captured with the top-view camera of the proposed method. Fig. 5. (b) shows a test on images captured with the top-view camera of the proposed method. As can be seen, the foreground is a blue hook. The red points are SIFT (scale invariant feature transformation) features [9]. The homography estimated from the matched features of the two images is represented as the movement from red points to green points. The dense optical flow computed with flownet2 [10] returns the pixel movements from the red points to blue points. Just as mentioned above, in the background, these two movements match. On the other hand, in the foreground, the homography and optical flow of foreground objects are not consistent. The result of foreground-object detection is shown in Fig. 5. (c), and comes from identifying the points for which optical flow and homography do not match. Fig. 5. (d) overlaps the binarized foreground mask in Fig. 5. (c) onto the image that will be used in stitching.

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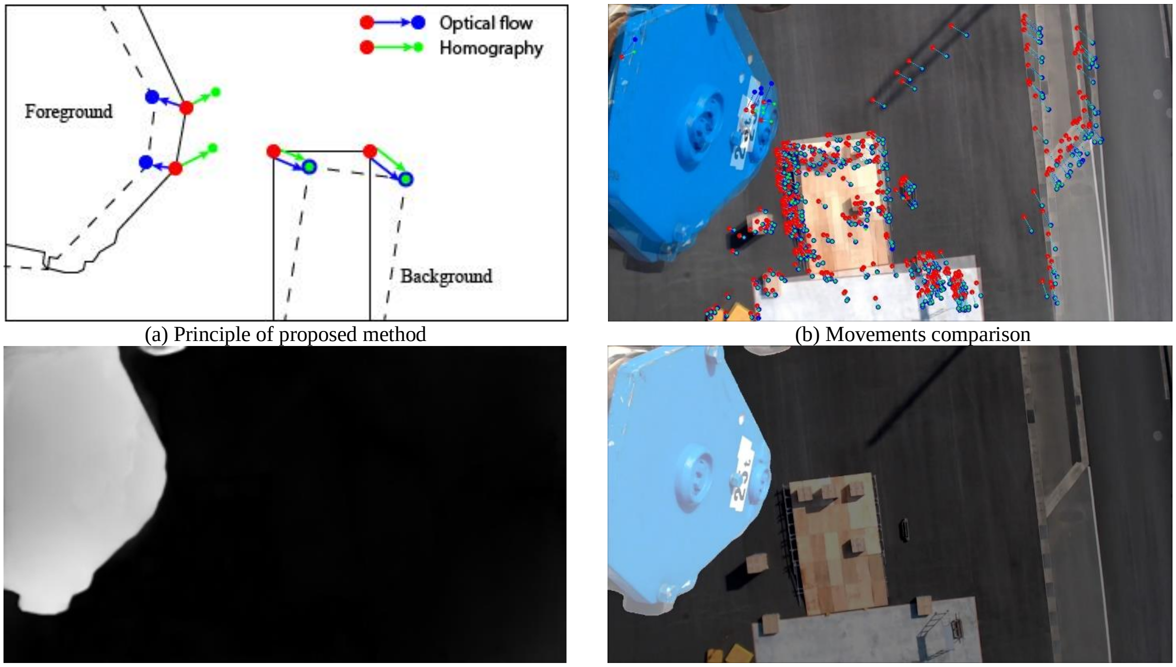


(a) Principle of proposed method

(b) Movements comparison

(c) Detected foreground mask of our method

(d) Comparison of binarized mask and image

Fig. 5. (a) A principle diagram of the proposed method to detect foreground by examine of the distance from the blue point to the green point. (b) A test result of the method on two images captured by the top-view camera showing sparse optical flow and homography. (c) Detection of foreground by comparing the difference between the dense optical flow and homography. (d) Comparison of binarized mask with the image.

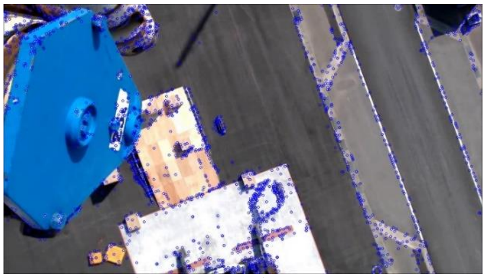
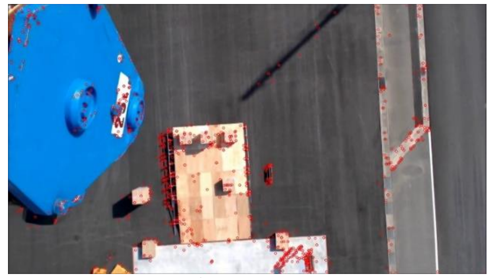
3. Workspace map generation with image stitching

The image-stitching problem is well understood. Image alignment and stitching through feature-based matching to estimate a homography are the most important steps. Fig. 6 shows the process of stitching two images into one panoramic image.

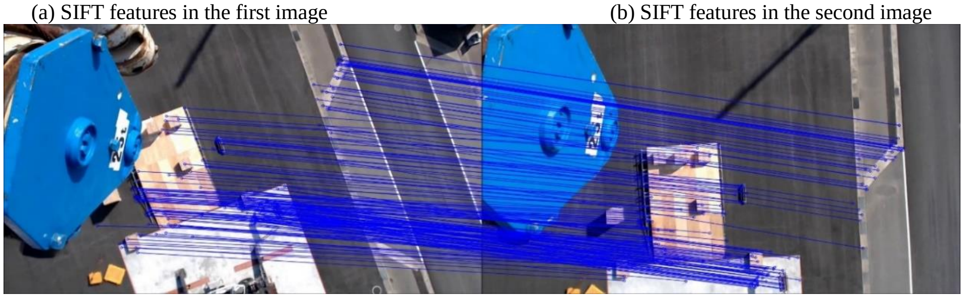
The first step is to find robust features such as SIFT features [9], KAZE features [11] in the two images. Here, SIFT features are chosen because their good scale invariance, rotation invariance and illumination invariance. As shown in Fig. 6. (a) and (b), SIFT features are extracted from each image. The second step is the estimation of the homography by matching the SIFT features detected the first step. To estimate the homography with the matched results robustly, the RANSAC (random sample consensus) algorithm is implemented [12], which robustly identifies inliers of the matched features and estimates the homography with high precision. Fig. 6. (c) shows the result of RANSAC inliers.

After the estimation of homography H from the matched features between the two images, the homography H is used to warp the first image with projective geometry. Coordinates in the image to be warped are represented as $P_i(x_i, y_i, 1)$. The corresponding point in the second image is $P_i'(x_i', y_i', 1)$. P_i' can be easily obtained with equation $w_i P_i' = H P_i^T$, where w_i is a scale parameter and H is a 3×3 matrix representing the homography. So all pixels in the first image find their corresponding point in the second image. Fig. 6 (d) shows the result after aligning the first image to the second image.

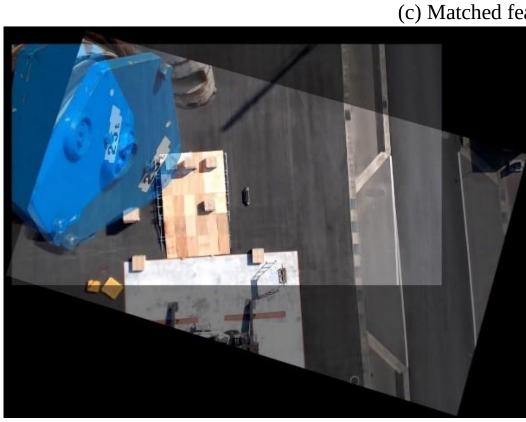
Once the images are aligned, they simply need to be blended together. Multiband blending is used for this process because of its good performance on many examples of image stitching [13]. Fig. 6. (e) shows the blended result of Fig 5. (c) using masks detected using the method proposed in section 2. To make the foreground mask more reliable, morphological dilation is applied [14].

(a) SIFT features in the first image (b) SIFT features in the second image



(c) Matched features of RANSAC inliers




(d) Aligned result according to homography (e) Stitching result

Fig. 6. (a)(b) SIFT features are detected from both images. (c) RANSAC inliers are extracted from the matched SIFT features. Homography is estimated with these RANSAC inliers. (d)With the applying of the homography estimated in (c), the first image is warped and aligned with the second image. (e) The result of stitching by applying multiband blending on (d).

4. Experiments with application of path location display

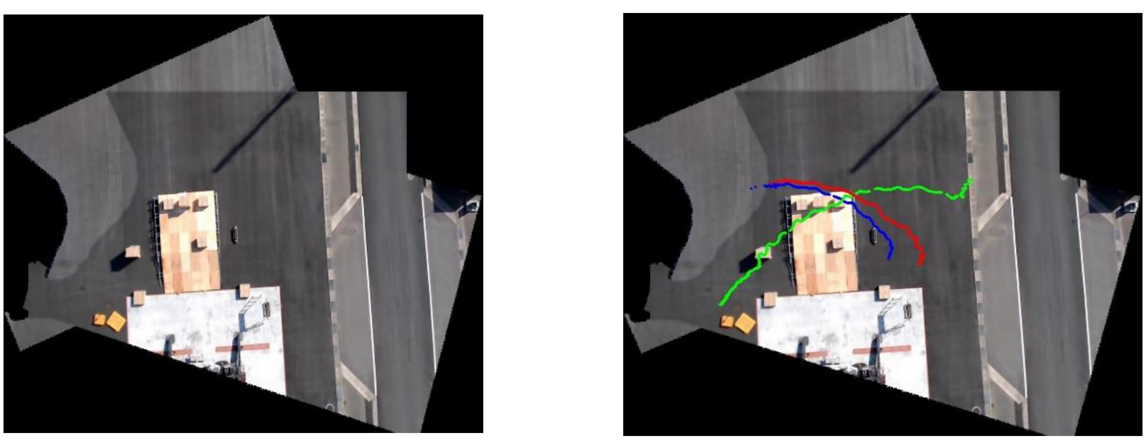
The methods described above were tested with prototype software to prove that the concept is feasible. The input is a video V_{pre} recorded in the pre-shooting under the conditions described in section 2. V_{pre} is a sequence of images from which blurred frames are excluded with a simple filter. Then several key frames for V_{pre} are selected automatically by considering the overlap ratio. A reasonable overlap ratio could ensure that there are enough features existing in the overlapped region. This could ensure the homography between tow images being estimated successfully. On the other hand, the overlap ratio can ensure that stitching one image to another with a significant non-overlapped area. The selected key frames are noted $k_0, k_1, \cdots, k_N$. The generation of the workspace map is made by the following two steps.

The first step is to compute a mask for each key frame. For each of the other key frames k_i, a foreground mask should be detected by computing the homography vectors $\boldsymbol{v}_{\text{homo}}(\boldsymbol{p})$ and optical flow vectors $\boldsymbol{v}_{\text{opt}}(\boldsymbol{p})$ for all the pixels $\boldsymbol{p}$ of k_i [10]. For this purpose, one support frame s_i was chosen for computing the homography and optical flow. The support frame s_i were chosen from a set of 20 frames near k_i in V_{pre} one by one to generate an optimal mask. This selection was done manually for the experiment in this article but can be automated in the future. Only three key frames were chosen from V_{pre} for these preliminary tests, which was not difficult to perform manually. From k_i to s_i, for all the pixels $\boldsymbol{p}$, $\boldsymbol{v}_{\text{homo}}(\boldsymbol{p})$ is computed by the homography. The homography H is a mapping from the key frame k_i to s_i, that is, all the pixels $\boldsymbol{p}$ of k_i is mapped to their corresponding locations $H(\boldsymbol{p})$ on s_{i}. Thus $\boldsymbol{v}_{\text{homo}}(\boldsymbol{p})$ can be computed by $\boldsymbol{v}_{\text{homo}}(\boldsymbol{p}) = \boldsymbol{p} - H(\boldsymbol{p})$. For $\boldsymbol{v}_{\text{opt}}(\boldsymbol{p})$, it can be directly estimated with flownet2[10]. Then the difference D between $\boldsymbol{v}_{\text{homo}}(\boldsymbol{p})$ and $\boldsymbol{v}_{\text{opt}}(\boldsymbol{p})$ for all the pixels $\boldsymbol{p}$ of k_i can be computed with $D = \|\boldsymbol{v}_{\text{homo}}(\boldsymbol{p}) - \boldsymbol{v}_{\text{opt}}(\boldsymbol{p})\|$. The foreground pixels $\boldsymbol{p}_{\text{f}}$ and the background pixels $\boldsymbol{p}_{\text{b}}$ vary a lot in the value of D. Thus, by filtering with a threshold, the foreground pixels $\boldsymbol{p}_{\text{f}}$ can be picked out as the foreground mask m_i with a binarization process.

The second step is to stitch the key frames to form the workspace map. First the base key frame k_{base} is chosen, and is usually the image lying near the center of the workspace. For each key frame k_i, its homography H_i to k_{base} is computed through the matched feature points in the region they share. The homography is a mapping transforming key frame k_i to k_{base} to form the aligned images. With multiband blending, these aligned images can then form the stitched workspace map [13]. However, the workspace may be too large for k_{base} and k_i to share a common region. The manual selection of the key frames from V_{pre} is constrained in that the near key frames must have a reasonable overlapping ration for the homography between two key frames can be calculated. If this condition holds, the homography $H_{i,i+1}$ ($H_{i,i-1}$) between two key frames k_i and k_{i+1} ($k_i \; and \; k_{i-1}$) can be computed successively. Then H_i can be recursively defined as $H_i = H_{i,i+1}H_{i+1}$ for $i < base$ ($H_i = H_{i,i-1}H_{i-1} \; for \; i > base$). This computation process should begin with the base key frame and extend out to both sides. These conditions ensure that all the information needed to warp and place the selected key frames in the correct positions can be calculated. A workspace map W can be generated by stitching k_i masked with m_i with respect to k_{base}. Fig. 7. (a) shows an example of W with three key frames chosen from V_{pre}.

One goal of this study is to utilize the workspace map W for displaying some information to assist the operator. Here an application to overlay the path of the boom on W as a simple and useful piece of information is proposed to assist the operator. Another video V was recorded under the crane's ordinary working conditions to test the process for overlaying the boom positions onto the workspace map W. The path of the boom head T can be identified in this input video V and overlaid on the workspace map W. For each frame $f_i \in V$, we computed the homography from f_i to W. Assuming the center of the top-view camera is always just below the boom head, the boom head position T_i on W is represented by the center position of f_i. By plotting T_i for all $f_i \in V$, the path of the boom head can be overlaid on W.

Fig. 7. (b) shows the results of displaying the boom head position on the stitched workspace map. Three videos were used. The first video was recorded under the constrained conditions described section 2 with only a blue hook as the foreground in frames. This video was used to generate the workspace map. The second and third videos are recordings of crane's ordinary working operations of moving an object with a hook. As shown in (b), the three paths consisting of many locations are clearly shown. Some short gaps appear in the blue and green paths due to the blurry frames that were removed from the sample videos. The software designed in this study successfully produced basic workspace maps.



(a) Stitching workspace map with three frames (b) Result of displaying boom head's path on workspace map

Fig. 7. (a) The workspace map is generated by stitching with three key frames from the pre-shot video. (b) Three clear paths are formed by locating the image's position on the workspace map.

5. Conclusion

The proposed prototype software with proposed methods can create a clear workspace map from videos recorded from the boom head of a crane. No ghosts were apparent in the maps generated and the locations of objects in the videos are clearly represented in the generated workspace map. All the location points formed a clear moving path in the workspace map.

More work is required before this technology is ready for commercial use. First, the generation of masks for key frames is not automatic in the process of this article. An automated process should balance camera motion and precise optical flow calculations. The general optical flow calculation method used above cannot give precise result when two frames vary greatly. Second, the hook's position represented in the workspace map could be helpful to operators, and the workspace map method can be extended to include this information. Third, some conditions may require a more-developed warping method for the image-stitching process. Homography used alone cannot deal with very complicated cases such as a workspace that includes tall buildings. Finally, research is needed into additional information that can be displayed in the workspace map, serving purposes beyond than representing the boom's path.

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How DEWA Increased Efficiencies and Value by Using Streamlined Project Management Processes

Tarek Hassan Tawfik - PMP, PMI – Case Study, Omran Al-Shamsi

Abstract

This study will presents the factors to achieve project management success; In terms of standards and methodology the organizations should adopt to achieve the values and benefits of project management. Multi-dimensional frameworks are validated and used in this study to measure project management performance and project success.

Dubai Electricity and Water Authority (DEWA) delivers worldclass services of electricity and water that meet the highest standards of availability, reliability and efficiency. DEWA serves over 842,000 customers across Dubai, a flourishing global city considered a leading hub of business activity in the Middle East and Northern Africa regions.

Since its merger in 1992 of the Dubai Electricity Company and Dubai Water Department, DEWA has evolved and grown, measuring and adjusting the ways it serves its customers and integrating project management across the organization.

Dubai has experienced an unprecedented growth over the last two decades that transformed the city and propelled its gradual rise to global business prominence. This growth added complexity to the already daunting task of providing water and electricity services to consumers and businesses in a region with a population that exceeds two million. In 2014 alone, water connections increased nearly 30 percent, rising from 23,350 in 2013 to 30,000. The power demand increased another five to six percent in 2015. (DEWA Annual Statistics).

DEWA's leadership knows that adhering to proven project, program, and portfolio management practices reduces risks, cuts costs, and improves success rates. Top champion organizations realize the right project, program, and portfolio management practices give them a competitive edge. But there's always more that can—and should—be done. For the past six years, we have been conducting additional research to determine which factors have the most impact on project success. Based on a rigorous statistical analysis, three things rise to the top when it comes to helping organizations save millions of dollars: drivers of project success: (PMI pulse of profession – 2018)

1. Investing in actively engaged executive sponsors
2. Avoiding scope creep or uncontrolled changes to a project's scope
3. Maturing value delivery capabilities

Introduction & Background:

Dubai has experienced an unprecedented growth over the last two decades that transformed the city and propelled its gradual rise to global business prominence. This growth added complexity to the already daunting task of providing water and electricity services to consumers and businesses in a region with a population that exceeds two million. In 2014 alone, water connections increased nearly 30 percent, rising from 23,350 in 2013 to 30,000. The power demand increased.

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“To keep pace with this growing demand for water and electricity services, the advent of green technologies and the push toward renewable energy, DEWA strives to achieve the leadership vision which was translated into the federal and local strategies. These include the UAE Centennial 2071, the UAE Vision 2021, the Dubai Plan 2021, and the Dubai Clean Energy Strategy 2050, ensuring the sustainable development of Dubai, to make it the happiest and smartest city in the

world,” said His Excellency Saeed Mohammed Al Tayer, Managing Director and CEO of DEWA. As more and more projects were initiated, DEWA’s leadership discovered that standard project management practices were not being observed across the organization, leading to decreased efficiencies, tempered innovation, redundant data, and an increased administrative burden on employees. At the time, DEWA relied on its 40 employed PMI certification holders to reinforce project management good practices. The number of certification holders continues to grow. DEWA now employs 60 PMI certification holders. DEWA’s leadership knows that adhering to proven project, program, and portfolio management practices reduces risks, cuts costs, and improves success rates.

Because project ideas and strategies must be linked with data, workflow, and business processes, and because the complexity within projects is increasing, DEWA needed a way to measure, integrate, and streamline its project processes and ensure consistent practices organization wide.
Companies develop methodology to provide some degree of consistency in the way that some projects are managed. These types of methodology are often based upon rigid policies and procedures but can be successful.

Good Methodology allow us to:

1- Shorten project Schedule.
2- Reduce and/or better control cost.
3- Prevent unwanted scope changes.
4- Plan for better execution.
5- Predict results.
6- Improve customer relationship during execution.
7- Provide senior management with better visibility of status.
8- Standardize Execution.
9- Capture best practices.

Successful development and implementation of project management methodology requires:
1- Identification of the most common reasons for change in project management.
2- Identification of the ways to overcome the resistance to change.
3- Application of the principals of organizational change management to ensure that the desired project management environment will be created and sustained.

Methodologies do not manage projects: People do. It is the corporate culture that executes the methodology. If this done successfully, then the following benefits can be expected:
1- Better control of project scope.
2- Lower overall project risk.
3- Better decision-making process.
4- Greater customer satisfaction, which leads to increased business.
5- More time available for value-added efforts, rather than internal politics.

Project management cannot succeed unless the project manager is willing to employ the system approach to project management by analyzing those variables that lead to success and failure:

1- Predicting project success.
2- Project Management Effectiveness.
3- Expectations.
4- Lesson Learned.
5- Best Practices.

Our organization and Throughout its strategic journey to realize its vision as a sustainable innovative world class utility, DEWA continues to develop and adopt methodologies that enables it to align with the UAE leadership ambitions and national plans, ensures stakeholders happiness, successful transition towards smart Dubai and excel! in the provisioning of electricity and water services. Therefore, DEWA recognizes the importance of having a strategy execution framework and methodologies that utilize portfolio, program, and project management as organizational-enabling practices to consistently optimize resources and time that leads to improved services, value to stakeholders and better social, economic and environmental results. The world’s population is having a major impact on the Earth’s environment, including the reduction of natural resources, and an increase in carbon emissions. This is the result of a number of factors including the current unsustainable lifestyle of the world’s population. In addition, we are working in DEWA to achieve and support Dubai’s Demand Side Management Strategy, to reduce energy and water demand by 30% by 2030, and the Dubai Carbon Abatement Strategy to reduce carbon emissions by 16% by 2021.

DEWA developed a unified project management approach based on benchmarking of best practices (PMI®, PRINCE2P® and ISO 21500 Guidance) to provide guidance on the management of portfolios, programs, and projects, integrated with DEWA business management framework and consistent across all divisions and departments within DEWA.
This approach aims at the following objectives:

1- Contributing to achieve DEWA's vision, mission and implementations of its strategic plan.
2- Introducing a unified and structured means of managing and controlling portfolios, programs, and projects in light of-and to deliver-organizational strategy across all divisions and departments within DEWA.
3- Incorporating a unified standard for project management, one standard concepts and terminologies throughout the organization.
4- Utilizing project management best practices to deliver DEWA projects in terms of scope efficiency, quality, time and budget.
5- Enrich DEWA employee's competitive capabilities in project management.
6- Providing support for DEWA PM I.REP (Register Education Provider) project management activities and maintaining License requirements.

DEWA Project Portfolio and project Management is a comprehensive view of corporate entire portfolio of projects and ability to prioritize and release programs/projects with alignment with DEWA strategic objectives. Adapt SAP best practice, International standards in PPM/PS processes.

Provide standardized platform (PMIS) for PPM/PS processes In Alignment with ISO 21500 guidance for Project Management, and PMI standards.

Standardize departmental processes within the division Better utilization of resources through Multiple Resource Scheduling (MRS).

Improve Tendering, Planning, Execution Reporting and Tracking of internal and external DEWA projects thru SAP PPM/PS Integration of the processes with Materials Management, Financial Systems, HR, and other SAP modules. KPI reports & dashboards that supports strategic and operational decision-making.

 DOI 10.3311/CCC2018-068

In order to foster increased competitiveness and sustainability, organizations are implementing projects to build their paths for the future. As such, the concept of project management has become an increasingly important subject in various business fields. According to Newton (2015), there are different ways in which projects can be approached. Various methodologies and/or frameworks have been developed in order to look at projects in their own practices. In line with this, Newton (2015) identified the key project management methodologies to include Agile, PMBOK, Six Sigma, PRINCE2, and Critical Chain. These are the most common project management methodologies that are widely used by project managers worldwide. In order to have a better understanding of the emerging topics in the project management field, these concepts are explored and linked to organizational success.

Agile Concept

Further, agile approach is one of the most common project management methodologies. As such, the agile project management (APM) can be described as the ideal model for modern and information age projects. According to Rico (2010, p. 37), "Agile Project Management (APM) is a new paradigm for managing high-risk, time-sensitive, research and development-oriented new product development projects." This means that APM is widely used for managing complex and modern projects within the constantly changing business environment. As clarified by Rico (2010), the theory of complex adaptive system suggests that modern complexities must be managed beyond the traditional management practices and principles in order to lead positive change. In other words, the cutting edge complexities must be overseen past the customary administration practices and standards, keeping in mind the end goal which is to focus on and lead positive change. This specific theory is linked to the agile PM methodology where the modern complex systems are subjected by the unstable market conditions.
As highlighted by Elliott (2008), agile project management places emphasis on throughput, teamwork and leadership. In line with this, the same author identified the different key agile principles to include:

- Focusing on customer value.
- Fostering iterative and incremental delivery.
- Provision of intense collaboration.
- Building of small and integrated teams.
- Self-organization.
- Small, continuous improvements.

In today's contemporary era, there is a need for responsiveness and agility in order to enable firms to cope with the unpredictability and changes in the global business arena. As such, the concept of agile project management was developed in order to address project complexities beyond traditional approaches. As highlighted by Cervone (2011) the agile project management approach was developed in order to emphasize two important concepts: (1) risk can be reduced by focusing on short iterations of clearly defined variables and (2) direct communication with stakeholders is emphasized in the development process in order to create effective project documentation. (Cervone 2011).

Value-driven projects

- In line with the agile project management concept, project success can also be achieved by utilizing value driven approach. This means that firms need to build value-driven relationships in consideration of the three project elements including business, project management office and project team (Faisal, Safitri and Dahlan 2013). This suggests that it is important for project managers to manage value-driven projects in order to foster project success in the rapidly changing global marketplace. As such, Faisal, Safitri and Dahlan (2013) noted that fostering value-driven projects can promote long-term commitment, relationship and mutual benefits that can lead to project success. Thus, value-driven projects is commonly guided by the value-driven project management model suggesting that successful projects are driven by certain values of project management such as time and cost of the project, transparency, company image, customer satisfaction and cross-functional interaction among others (Polkovnikov and Ilina 2014). This suggests that value-driven projects produces user-valued features particularly

 DOI 10.3311/CCC2018-068

in terms of making sound decisions so as to promote project success. As highlighted by Collier (2012), value-driven development is about creating projects that has user-valued features that users care about and understand. Thus, value-driven projects can enhance the effectiveness and sustainability of projects that can affect their success. Figure 1 shows the framework of the value driven relationship between the three important elements of project success (the business, the project management office and the project team) and change management.

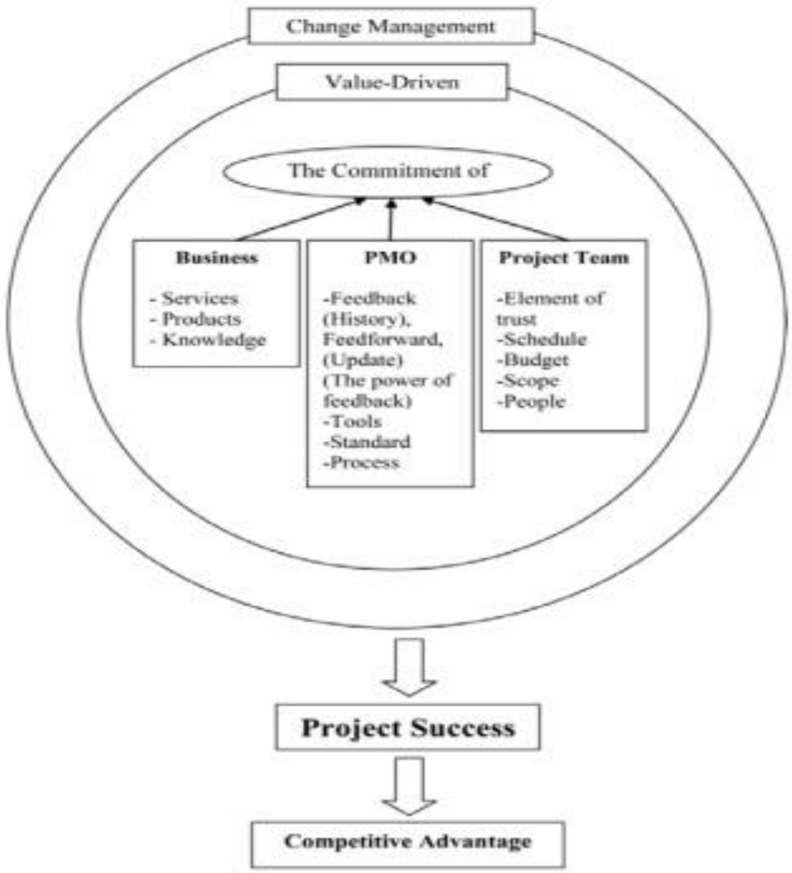
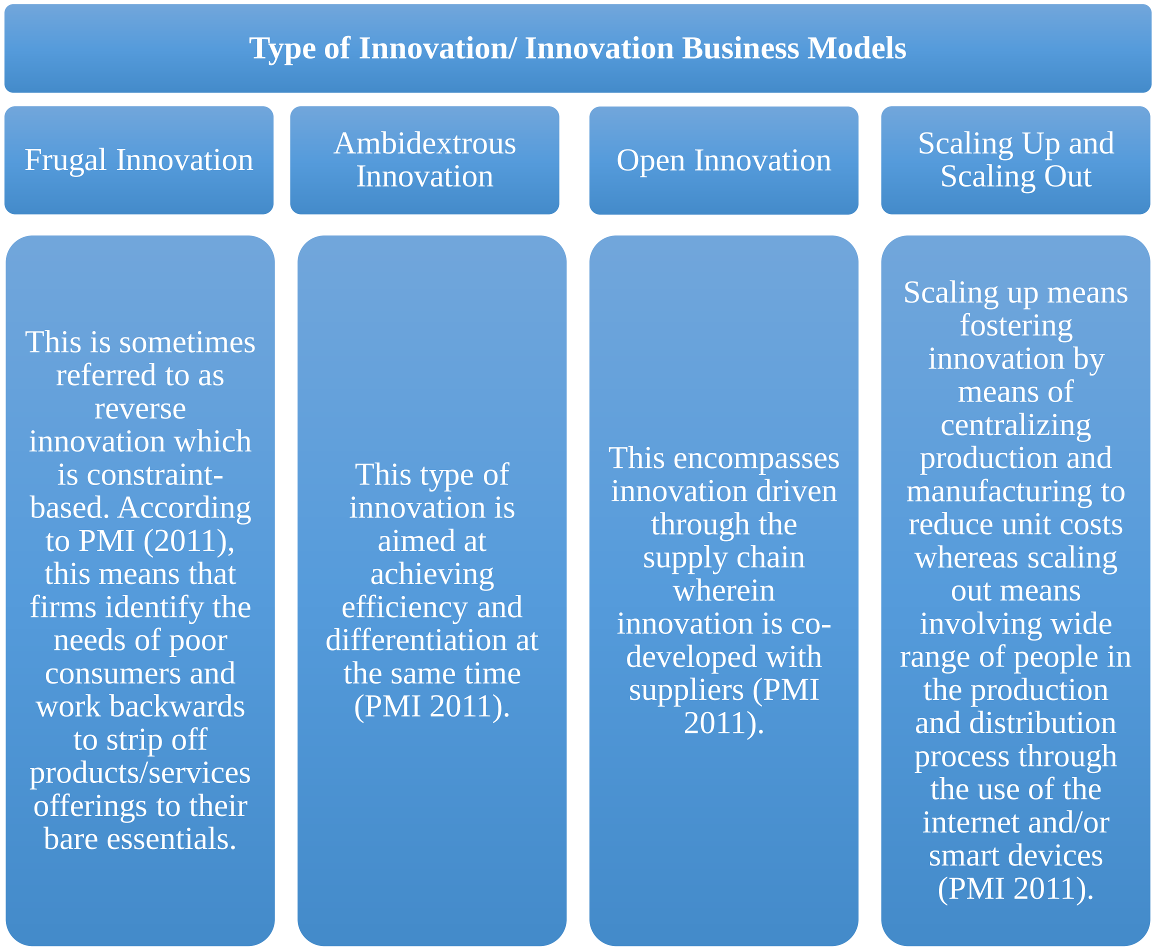


Fig. 1 Framework of Value Driven Relationship (Faisal, Safitri and Dahlan 2013)

1.1. another five to six percent in 2015.2Structure

Managing Projects for innovation

Moreover, the concept of managing projects for innovation has also become an important subject in the field of project management. This is due to the significant role of innovation in the sustainability of businesses in the modern world. According to The Project Management Institute (PMI) (2011), modern businesses particularly in developing economies are becoming promoters of business innovation in an effort to foster competitiveness and sustainability. As explained by the same author, modern businesses are constantly attempting to come up with new product/service developments that are cheaper, reinvent production and distribution systems and experiment on new business models so as to achieve innovation. As such, managing projects for innovation has become an important driver of competitiveness and sustainability.
In order to understand the concept of managing projects for innovation, it is important to know the different definitions and/or principles of innovation. Table 1 shows the new definitions of innovation as adapted from the Project Management Institute (2011).



In line with the different types of innovation and innovation business models, PMI (2011) identified the different innovation areas wherein most of them involve industry convergence (shown in figure 2). According to the same author, the six innovation areas include mobile technology, mobile money, alternative energy, mobile medicine, convergent healthcare and human 2.0.

In relation to managing projects for innovation, one of the most effective tools in resource allocation is project portfolio management. It is used to enable the management to select projects with the highest potential to become new products and services winners in the future. In a study by Stadnick (2007), the author suggested that project portfolio management methodology contributes to innovation. Thus, managing projects for innovation is based on the principles of the management and innovation theories suggesting that innovation is an important aspect in firms' growth strategies particularly in project-based firms. As highlighted by Keegan and Turner (2000), managing projects for innovation is a new management paradigm in achieving project goals. This suggests that designing innovative products and services can be viewed as one of the most important capabilities of modern businesses in order to enable them to address and meet the changing and evolving customer requirements.

Complexity within projects

Therefore, in line with managing projects for innovation, it is important to understand the complexities and uncertainties within projects. According to Ameen and Jacob (2009), modernity influences project complexities particularly in relation to managerial demands due to different situations faced in project development and implementation. This is based on the complexity theory wherein it provides varied view of management particularly

 DOI 10.3311/CCC2018-068

in relation to project management. As such, project complexity can be defined as “consisting of many varied interrelated parts and can be operationalized in terms of differentiation and interdependency” (Baccarini 1996 cited in Ameen and Jacob 2009, p. 6). Thus, Dombkins (2008) cited in Ameen and Jacob (2009, p. 5) noted that in lieu of the complexity theory, “complex projects have a high degree of disorder and instability” because they can be described as complex evolving systems. As highlighted by Baccarini (1996, p. 201), it is important to acknowledge the significance of complexity in project management because it can help in determining the planning, coordination and control requirements. The same author further explained that complexity within projects can hinder clear identification of objective and goals of major projects that can have profound impact on project outcomes.

As proposed by Baccarini (1996), it is important to identify the type of complexity within a project in order to determine the most appropriate project management process to be implemented in dealing with complexity. In line with this, complexity within projects can best be understood based on the different typologies of complexity.

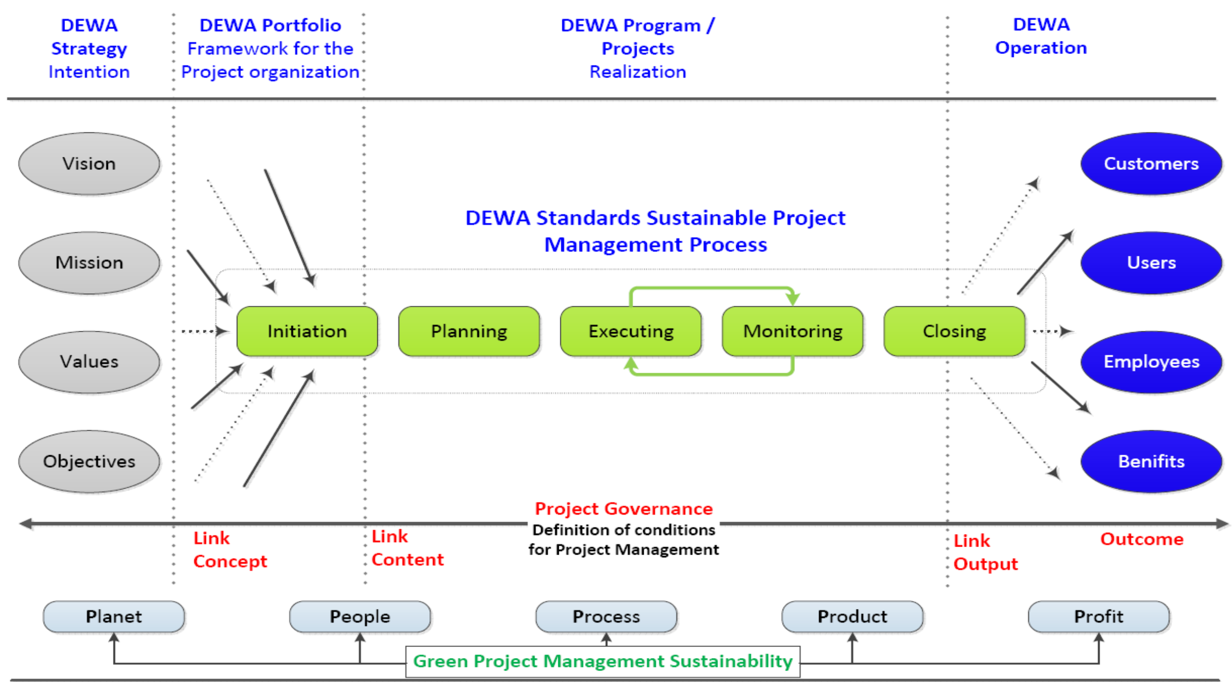
- Complexity of Faith - this refers to complexities involved in the creation of something different or unique or solutions toward solving new problems (Ameen and Jacob 2009). Thus, this type of complexities can arise within projects due to uncertainties.
- Complexity of Fact - this refers to uncertainties in dealing with large amount of independent information (big data) (Ameen and Jacob 2009).
- Complexity of Interaction - this refers to complexities present in interfaces (i.e. ambiguity, neutrality, etc.).
- Organizational complexity - this describes differentiation in the number of hierarchical levels and/or units, and division of tasks. As explained by Ameen and Jacob (2009), differentiation has two dimensions - vertical and horizontal differentiation.
- Technological complexity - this describes complexities in the areas of operations, characteristics of materials and characteristics of knowledge (Baccarini 1996 cited in Ameen and Jacob 2009).
- Social Intricacy of Human Behaviour - this describes uncertainties in human responsiveness particularly in facing collective challenges as a team or society as a whole (Oehmen, et al 2015).
- Uncertainty of long lifecycles - this refers to the different factors increasing uncertainties to which project activities are exposed such as communication infrastructure, scale of human activity and considerations of long term lifecycles among others (Oehmen, et al 2015).
- Understanding complexity within projects is important in order to allow project managers to better ideas on how to handle complex projects and address difficulties in coping with the increasing complexity within the project management discipline.

In DEWA during the project phases of designing and civil construction, the stages might affected with the complexity of delaying such as, the drawings that can’t be agreed among the stakeholders because of the wrong calculation that is determined by the concern group. Therefore, DEWA project team will conduct workshops to discuss and agree regarding any conflict may occur during the design stage. Furthermore, civil construction work, consider an essentials due to the limited number of civil contractor in the market due to increasing of economical growth in Dubai along with highly demand in civil contractions. Many of DEWA projects get delayed due to the non-availability of an appropriate civil contractor that affect the project progress in terms of delaying milestone which is affect the OBS KPI. DEWA has arranged trainings to those civil companies along with having a meeting coordination quarterly to track the project life cycle with the avidness of any further issue.

Finally, in understanding the concept of project management, it is important to consider the roles of project managers in implementing successful projects. According to Kerzner (2017), in a diverse business environment wherein project managers interact with on a daily basis, competitive edge is also very important. This is because nowadays, there are already many project managers who are equally as talented and skilled in the technical aspects of project management as the others are.

While it is undeniable that in a project management position, technical skills or hard skills are important and that in most cases, the project manager’s success is being measured by the technical aspect of his job, it is also apparent that nowadays, a project manager’s soft skills are also increasingly becoming more relevant and significant than it was

before due to the changing nature of the business environment (Kerzner 2017). The project manager's soft skills are therefore considered as his competitive edge over his competitors and serves as the foundation of his effectiveness in fulfilling the functions and roles of a good project manager (Gillard 2009).
Due to the many changes in the business environment, the roles of project managers are also fast changing and the emphasis on the development and exercise of soft skills among project managers is more relevant and significant today than it was before. Nowadays, project managers are being taught the importance of honing their emotional intelligence and leadership skills in order to fulfill their job roles more effectively (Azim 2010).
In addition, the expected productivity levels of project managers are greater nowadays due to the changing and increasingly becoming competitive nature of the industries. As a result of the difficult times and complexities within projects, project managers are forced to exert more effort when it comes to exercising their leadership capabilities as the success of the company depends heavily on them (Kerzner 2017). Thus, there is no doubt that indeed, the changing nature of the business environment is what continuously pushes project managers to shift their focus from simply developing their technical skills but also enhancing their soft skills.



The Solution

DEWA's leadership established a dedicated team, including senior management representatives, to begin implementing SAP software for its portfolio and project management and enterprise asset management systems. DEWA launched a multi-phase implementation project that concluded at the end of 2015. The first phase began in October 2009 with a focus on customer services. Phase II followed in January 2012. It focused on procurement, stores, finance and human resources. The third and final phase comprises enterprise asset management generation, projects and portfolio management for generation, transmission and water, fleet management, business preparation and consolidation processes for the financial department, and a project system for business support projects. Initiated in March 2014 and launched in

September 2016, phase III aimed to standardize, simplify, and automate the enterprise asset anagement and portfolio project management/ project system processes. Recognizing that active participation and support of employees was a key factor in the successful implementation of the software, DEWA held educational sessions to increase awareness about the project. This would enable employees to more effectively utilize the system, thereby maximizing its benefits.

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With the software in place, DEWA is better able to supplement its existing project management efforts, including alignment of capital and operational spending, planning and budgeting, and early identification of opportunities and risks.

“SAP software provides us with integrated solutions that contribute to DEWA’s objective to achieve sustainable development, especially as indicated by international best practices,” said Al Tayer. “One of our goals is that our processes be world class, yet simple and easy to use.”

Achievements

As a result of this implementation, DEWA is now more efficiently managing projects that support its strategic plan and the four distinct perspectives in its balanced scorecard: financial, internal processes, customers, and the support of learning and growth.

DEWA has replaced more than ten legacy systems in its finance and accounts, consumer self-services, procurement and human resources areas. Project highlights include reducing:

- The monthly closure of accounting books from 20 days to five
- Budget checking from three days to one minute
- The number of steps in the utility connection process from nine to one
- The time it takes to move purchase requisitions into the

payment cycle from 60 days to 15 In 2012, DEWA won the Bronze Quality Award from SAP for Europe, the Middle East, and Africa in the Large Implementation category. It was recognized for its use of a suite of SAP solutions to improve efficiencies throughout the organization. “This award reaffirms our leadership and our renewed drive toward more achievement and innovation,” said Al Tayer.

Through DEWA’s commitment to the delivery of sustainable electricity and water services at world-class levels of reliability and efficiency, and its continued appreciation of the value of project management, the United Arab Emirates, represented by DEWA, ranked first in the world for getting electricity in the World Bank’s Doing Business” 2018 report.

Recommendations:

While DEWA is known for completing successful projects, it is still important to consider that there is always room for improvement. Thus, this set of recommendations are proposed for the DEWA management to further improve their existing project management activities and practices.

- In relation to managing complex projects, it is recommended for project managers to acknowledge complexities and develop managerial sensitivity toward project uncertainties in order to allow them to continuously develop solutions or revise solutions toward the identified aspects of problems. It is important that project managers don’t rely on treating complexity as simple because it can only lead to chaotic projects (Oehmen, et al 2015).
- It is important for project managers to have a better understanding of complexities within projects and to be engaged as early as possible and during initiation phase. As such, it is recommended for DEWA management to invest in continuous trainings to develop skills and knowledge of project managers particularly in relation to managing complex projects. Examples of trainings include communication skills training, managing complex projects workshop and implementing technological structures program. (DEWA is a PMI R.E.P Register Education Provider for PMI Activities)

Provide project managers understand different project management methodologies and tools in order to permit them to identify issues that may arise during planning and implementation of innovation projects. This will allow project managers to have opportunities to tailor project management tools in accordance to the demands and requirements of the projects (Yakovleva 2014):

- Enhancing project manager skills by Incorporating innovation concepts
- Embracing changes and ability to take action.
- Digitizing and centralizing works through and enterprise management systems. PMIS (Project Management Information System Tool), in DEWA is SAP.
- Project Manager recommended to be courage and has the legitimate power to solve project issues, stakeholder's engagements and customer requirements proactively.
- Project Managers should be innovative and creative in projects.
- Project Managers should improve code of ethics and professional conducts.
- Project Managers should contribute by sharing lessons learned and best practices to all future projects.
- Project Managers to be aware of culture differences specially in multicultural organizations.

Conclusion

DEWA continues to make inroads when it comes to incorporating project management concepts and terminology throughout the organization. The SAP software enables DEWA employees to structure projects more consistently, transfer knowledge, and periodically evaluate methodologies to identify improvement opportunities—all of which leads to increased efficiencies, value, and customer satisfaction.

Building the Future

As the first organization in Dubai and the UAE to become a Registered Education Provider (R.E.P.) DEWA is well equipped to provide the appropriate educational tools to keep employees up to date with project management standards. As an R.E.P., DEWA delivers accredited courses and activities directly to its employees. This results in considerable savings. "We consider our employees the most important pillar of our success," said HE Saeed Mohammed Al Tayer, MD and CEO of DEWA. "We take priority in involving staff in all initiatives and projects."


Project Management Institute
RECOGNIZES THAT
Dubai Electricity & Water Authority
IS HEREBY APPROVED AS A
Registered Education Provider (R.E.P.)
Global Provider Enrollment Level
For The Period 01 Jul 2017 To 30 Jun 2018

In addition to PMI courses, DEWA collaborates with other institutions of higher learning to assist students with earning Bachelor's degrees in electrical and mechanical engineering. With an eye to helping build the future workforce for the renewable energy and sustainability sectors, DEWA launched the Renewable Sustainable Energy Program for high school graduates. As of 2017, 30 students were enrolled—20 at the University of Sharjah and 10 studying abroad.

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Identification factors influencing accessibility of credit for small and medium contractors in the construction industry

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Abstract

Small and medium enterprises (SMEs) have an important role in the economic development in South Africa. (SMEs) caused competition becomes increasingly fierce. This made construction (SMEs) experiencing more challenge to be able to access credit from financial institution. This paper aims to propose a conceptual framework for credit accessibility among construction SMEs. Several factors are preventing SMEs contractors in accessing credit from financial institutions such as: lack of collateral, high interest rate and bank changes, lack of owner's contribution, lack of good business plan development, lack of excellent managerial skills, lack of business skill and lack of binding building contact agreements. The survey method and self-administered questionnaires were used for data collection. 179 respondents took part in the survey. Data was analysed with binary logistic regression. The results indicate that Age of the firms, ownership structure, company tax number, and location of the business, current position, managerial competencies, and incorporation are significant determinants of credit accessibility for construction SMEs. These findings could be useful to others SMEs sectors in identifying credit approval in credit application from the financial institution in South Africa.

Keywords: Credit accessibility, factors influencing, SMEs contractors, South Africa

1. Introduction

Small and medium enterprises (SMEs) are increasingly seen playing an important role in the economies of many countries. Thus, governments throughout the world focus on the development of the SME sector to promote economic growth. In South Africa, SMEs contribute 56% of private sector employment and 36% of the gross domestic product Ntsika Enterprise Promotion Agency, [18]. South Africa suffers from high unemployment with an official estimate of approximately 24.5% of the economically active population unemployed (Statistics South Africa, 2009). One of the best ways to address unemployment is to leverage the employment creation potential of small businesses and to promote small business development (Fin Mark Trust, 2006). The National Small Business Act of South Africa of 1996, as amended in (2003), describes SMEs as a separate and distinct entity including cooperative enterprises and

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non-governmental organizations managed by one owner or more, including its branches or subsidiaries if any is predominantly carried out in any sector or sub-sector of the economy mentioned in the schedule of size standards.

Despite their importance to the economy in South Africa, small and medium construction enterprises (SMEs) sector is described as largely underdeveloped and lacking the managerial and technical skills and sophistication enjoyed by larger well established firms [8].[15] opined that lack of knowledge including knowledge of pricing procedures, contractual rights and obligations; law, management techniques and principles as well as technology were a challenge to construction SMEs.

Furthermore, SMEs are more likely to have limited formal education, which is based on a construction craft or trade training such as carpentry, plumbing, electrical installation and bricklaying. This training is probably in the form of learnership [7]. Past studies in South Africa revealed constraints and challenges of capacity and financial resources among SMEs [9]; [3].[12] inferred that SMEs are not able to access finance or credit hence it stifles their growth and capability.

The concept of credit has been in existence as long as there has been civilization. It predates, by a considerable length of time the use of money, and written references to it appear as far back as in the code of Hammurabi, established around 1750 B.C. From its beginnings, credit has been used as a selling tool, to bind customers to a particular vendor and allow them to acquire more substantial goods for which they do not have the necessary capital [14]. The theory of credit emphasizes that financial institutions would be more willing to extend credit if, in case of default, they could easily enforce contracts by forcing repayment or seizing collateral. The amount of credit in a country would depend to some extent on the existence of legislation that protects the creditors' rights on proper procedures that lead to repayment [1].

The initial capital and expansion capital fund for South Africa construction SMEs has been a perpetual problem even though the government continuously strives to empower this sector into the mainstream economy. Credit gap still exists between the supply capabilities of financing sources and the demand needs for capital for construction SMEs. According to [2] Confirmed that Small and medium enterprises therefore have been one of the major areas of concern to many policy makers in an attempt to accelerate the rate of growth in low-income countries. In spite of this potential, a number of problem among which access to funds is a major concern confronting the growth of SMEs sector? In most countries, banks are major players in the provision of debt capital to SMEs. They do so by providing short, medium and long-term loans, and other credit facilities like letters of credit, investment advice, etc.

This study therefore filled the gap using the Binary Logistic Regression analysis to establish which variables are the more critical as well as the strength of the inter-relationship between the dependent variable which is access to credit by the construction SMEs and a number of explanatory or independent variables such as Age, ownership, location of the business, accounting records, business plan personal collateral, current position, firm tax number.

2. Literature Review

2. 1 Challenges preventing construction SMEs from accessing credit

According to [4]**,** results, the factors that stifle SMEs from accessing credit are, management expertise, high default rate and monitoring as the challenges banks faced in giving credit to SMEs. [6] Found that the key challenges that make it difficult for SMEs to access finance include policy regulation, inadequate financial infrastructure, stringent collateral security requirement, and lack of institutional capacity of SMEs sector. The key barriers identified include informational barriers, lack of managerial skills within SMEs. [17] found that financial activities such as business registration, documentation/recording, business planning, asset ownership, impact heavily on SMEs access to bank credits.

Other challenges that SMEs encounter when trying to access finance can be due to an incomplete range of financial products and services, regulatory rigidities or gaps in the legal framework, lack of information on both the banks and the SMEs side. Banks may avoid providing financing to certain types of SMEs, in particular, start-ups and very young firms that typically lack sufficient collateral, or firms whose activities offer the possibilities of high returns but at a

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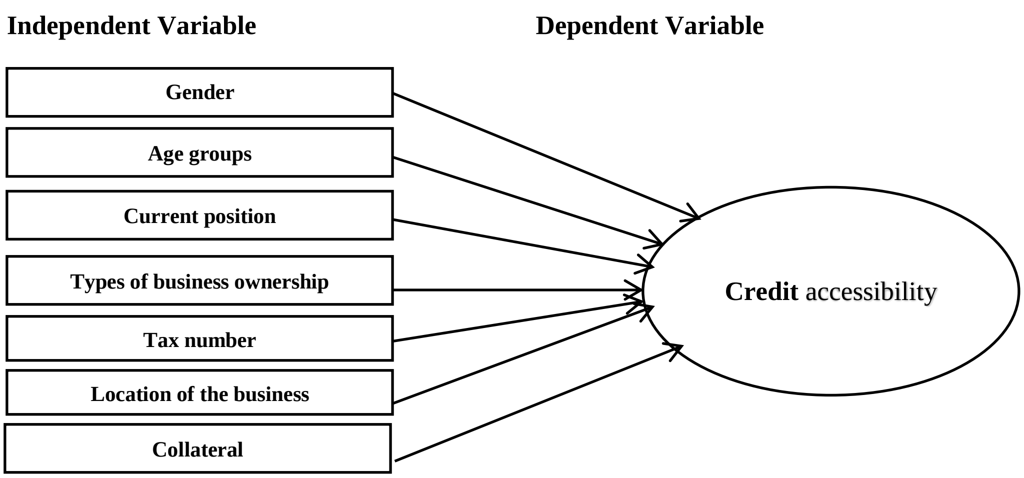
substantial risk of loss. There are many challenges to construction development and growth. These include policies regulations, inadequate financial infrastructure, firm regulations, trade regulations, tax regulations, changing government policies, tax rates, corruption, labour regulations, cost of capital, and keen competition for limited opportunities [15].[13] argued that factor like availability and cost of finance are the most common constraints faced by SMEs. Others are lack of collateral, informational barriers, regulations and rules that impede construction firms access to finance, the legal framework and policies around investment and financial institutions (FI's) lending are fundamental, lack of access to appropriate technology, weak institutional capacity, lack of management skills and training in the construction firms, and lack of proper book keeping. The legal and regulatory frameworks that exist in Ghana also fail to provide the right support infrastructure to facilitate SMEs lending by the financial institutions. The lack of collateral, lack of proper financial management, lack of fiscal incentives for SMEs, strict prudential regulations which restrict flexibility of FI's, unduly complex or onerous administrative procedures and even simply the lack of a consistent definition or enabling law for SMEs are some of the impediments to SMEs financing. Even though SMEs tend to attract motivated managers, they can hardly compete with larger firms.

[5] reviewed that entrepreneurs face several problems in their efforts to access finance, particularly from banks; viz., lack of collateral security, refusal to use own collateral, failure to make a remarkable own contribution, blacklisting, failure to review attractive financial records and/or business plans and high risk of small entrepreneurs. [11] explicates that lack of collateral is the most widespread problem, particularly if the entrepreneur is applying for working capital. Other issues affecting the decision to provide finance include blacklisting, and inadequate financial records. The report concluded that, based on international comparisons, for a significant proportion of unsuccessful applicants, the failure of the application would not seem to be entirely unreasonable.

[19] The Organization for Economic Cooperation and Development (OECD, 2006) argued that banks may avoid providing finance to certain types of SMEs, in particular, start-ups and very young firms that typically lack sufficient collateral, or firms whose activities offer the possibilities of high returns but at a substantial risk of loss [19]. It can be suggested from these discussions that different set of challenges prevents SMEs from accessing finance. Hence, the importance of determining the challenges faced by SMEs in the South Africa construction industry from accessing credit.

2.2 Conceptual framework

The conceptual model indicates the relationship of the demographic characteristics of the SMEs respondent and the company profile. These variables include; gender, age group, current position, company tax number, location of the company, type of business ownership, collateral and credit accessibility.



Diagrammatical Representation Showing the Independent Variable linked to the Dependent Variable Credit Accessibility

2.2 Operationalisation of the conceptual framework

The model is made up of dependent variables which were dichotomous; credit accessibility defined by (I did access credit and did not access credit) and (I accessed full credit and I accessed partial credit) and independent variables which are; gender, age group, current position, type of business ownership, business tax number, location of the company and collateral. The mathematical model 1 which is a general equation for logistic regression was used for this study to predict the independent variables influence on credit accessibility. This can be written as:

$\ln (p/1\text{-}p) = \beta 0 + \beta 1x1 + \beta 2x2 + \ldots + \beta kxk$…………………………………………………………………..(1)

The specific logistic regression for the study was modelled as follows**:**

$\ln (p/1\text{-}p) = \beta 0 + \beta 1\text{Gender} + \beta 2\text{Age Group} + \beta 3\text{CurPostion} + \beta 4\text{TypesBusOwnSh} + \beta 5\text{TaxNo} + \beta 6\text{LocBus} + \beta 7\text{Collateral}\ \varepsilon$

3. Research method and design

A quantitative philosophy were adopted for this study, which involved the use of structured questionnaire in an in-depth survey of the objectives set in this research.[2] describes a survey as a quantitative or numeric description of some fraction of the population – the sample, which enables researchers to generalize their findings from a sample of respondents to a population within the limitations of the sampling method. Convenience sampling which is a non-probability method was used where the researcher selected sample members to conform to the required criterion. The study population consisted of contractors registered with the CIDB. These were contractors registered from grade 1 to 6. The questionnaires were completed anonymously; therefore, the collection of the data and the presentation of this report cannot harm the respondents or their employing organizations in any way. 179 SMEs completed the questionnaire survey in the period August to November 2017, using the drop and collect method and email. [3] supported this approach. This ensured the increase of the response rate. Content validity was conducted on the questionnaire using pilot study administered to 30 construction SMEs. The content validity determined the clarity and content adequacy of the questions asked. Furthermore, it validated the time taken to complete the questionnaire.

The questionnaire included personal questions on age, gender, population group, education qualification, marital status, current position and years of experience in business. Other sections included company profile namely location of the business, ownership, construction industry development board (CIDB) grading, number of full time employees. Requirements of financial institutions e.g. collateral and tax number. It is worth noting that not all these variables were included in two models for credit accessibility i.e. to predict full credit they applied for or any credit at all. The dependent variable for full credit was informed by, whether the SMEs received full credit or part of the credit. On the other hand, the study also established whether the SMEs received the credit or did not receive credit. Statistical Package for Social Sciences (SPSS) version 22 was used to perform the binary logistic regression analysis on this dichotomous outcome.

Binary logistic regression models with dichotomous responses as dependent variables of Yes or No were modelled. Yes response was defined as having accessed credit and No accessed part of the credit. The second dependent variable defined “Yes” as accessed credit and “No” did not access credit. For analysis to be conducted, the responses of the dependent variables were coded as 1 and 0, for “Yes” and “No” respectively. The independent variables of the logistic regression model were coded. They conformed to the demographic and socio-economic characteristics of the SMEs: *gender* if male 1 and female 2; *age group,* 30 years and below 1, 31 years to 39 years 2, 40 years to 49 years 3 and 50 years and above 4; *current position,* director 1, owner 2, manager 3 and manager/owner 4; *ownership*, sole proprietorship 1, partnership 2, limited partnership 3, limited Liability company 4, corporation (for-profit) 5; *tax number* No, 0 and Yes, 1; *location of business,* city of Johannesburg Metropolitan Municipality 1, city of Tshwane Metropolitan Municipality 2, Ekurhuleni Metropolitan Municipality 4, West Rand District Municipality 4; *collateral* No, 0 and Yes, 1.

Logistic regression is recommended over linear regression when modeling dichotomous responses and allows the researcher to estimate probabilities of the response occurring [20]. The logistic regression equation takes the following form

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$\ln (p/1\text{-}p) = \beta 0 + \beta 1x1 + \beta 2x2 + \ldots + \beta kxk$……………………………………………………………………..(1)

Where p is the estimated probability of passing, and x1, x2, …, xk are independent variables.

The estimated probability of the response occurring or passing (p) divided by the probability of it not occurring or not passing (1-p) is called the odds ratio. Maximum likelihood method is used to estimate the odds ratios of the model. Values of odds ratios higher than 1 indicate positive association between the variables, odds ratios equal to 1 indicate no association, while odds ratios lower than 1 indicate negative association between each independent variable and the dependent variable of the model. Furthermore, in order for an independent variable to be a predicator of the dependent variable the p-value should be less than 0.05 at 95% confidence, which connotes its significance in the model. In achieving a fitting model the Hosmer-Lemeshow goodness of fit test should be significant i.e. the value should be greater than 0.05 [20].

The factors preventing SMEs from accessing credit were measured using Likert scale of 1 to 5. 1= Strongly disagree (SD), 2= Disagree (D), 3= Neutral (N), 4 = Agree (A), 5= Strongly agree (SA). The Likert-scale questions are discussed based on Mean Score comparison in interval scale. Hence, the difference between the upper and lower ends of the used scale is 4.0 since there are five points. Each range can be equated to 0.80 because the extent of the range is determined by a division between 4.00 and 5 (4/5). However, in the current study the intervals are as stated. The meaning of the intervals will change based on the questions asked by the researchers:

$> 4.21 \leq 5.00$ Strongly agree; $> 3.41 \leq 4.20$ Agree; $> 2.61 \leq 3.40$ Neutral; $> 1.81 \leq 2.60$ Disagree; $> 1.00 \leq 1.80$ Strongly disagree.

4. Results and discussions

The results indicates that male respondents were the majority than female respondents, at 63% to 37% respectively. Majority i.e. 51% of the respondents were in the age group between 40-49 years old. 82% of the respondents occupied the position of owners. 98% of the SMEs are sole proprietors. Furthermore, majority i.e. 41% of the SMEs were located in the city of Johannesburg metropolitan.

Table 1 indicates that the SMEs respondents strongly agreed that lack of collateral, lack of cashflow statement and owners equity were hindering SMEs from accessing credit from financial institutuions. The means were in the band of 4.21 to 5.00. Lack of collateral as a challenge was in line with the study of [6], [11], [13]. The sector of the bussiness, lengthy and vigorous procedure for credit application, high interest rates, location of the business were in the band of 3.61 to 4.20 suggetsing that the respondents agreed that they contributed to their difficulty of obtaining credit. Furthermore, the SMEs respondents disagreed that lack of appropriate eduaction and training, and lack of managerial ability were hindering them from accessing credit. These two constraints were in the band of 1.81 to 2.60.

Table 1: **Contraints in obtaining credit**

Constraints of credit accessibility	Mean	Stdev.	Rank
Lack of collateral	4.69	0.58	1
Lack of cash flow statement	4.51	0.98	2
Owner’s equity	4.39	1.01	3
Sector of the business	4.14	1.21	4
Lengthy & Vigorous procedure for credit application	4.13	1.37	5
High Interest rates	3.81	1.51	6
Location of the business	3.76	1.27	7
Lack of good reference on integrity	3.03	1.66	8
Lack of awareness of existing credit schemes	2.97	1.71	9
A general lack of experience and exposure on construction project	2.75	1.73	10
Lack of information on the cost obtaining such service	2.72	1.74	11
Lack of appropriate education & Training	2.21	1.68	12
Lack of managerial ability	2.09	1.59	13

Conclusions

The study elicited information from SMEs personnel who are conversant with the credit accessibility within their enterprise. The study found that SMEs are stifled from accessing credit because of lack of collateral/security, lack of cash flow statement and owners' equity. However, despite the constraints of accessing credit, which could be an obstacle to credit accessibility, the results suggest that majority of SMEs received credit whether full credit or partial credit. However, despite the SMEs obtaining partial credit it can hinder their progress. It can be suggested that when construction SMEs receive part of the credit they might apply for credit in other financial institutions or request financial assistance from friends in order to cover for the deficit.

Recommendations of the paper

Based on the conclusions, the study recommends the findings to different stakeholders, that is:

Recommendations to government

The government needs to encourage construction SMEs to approach commercial financial institutions to apply for credit as majority of SMEs obtained credit from them. The notion that commercial financial institutions reject or deny SMEs credit should be argued with caution as this study indicates that majority of SMEs acquired their credit from commercial financial institutions. The government needs to inform financial institutions not to be too stringent with collateral (security), owners' equity and cash flow statement as these are the constraints impeding SMEs from credit accessibility.

Recommendation to financial institutions

The financial institutions should be aware of this constraints construction SMEs encounter in accessing credit. Collateral (security), owners' equity and cash flow statement should not be mandatory requirements in order for SMEs to acquire credit. Other requirements should be suggested which will make it easy for SMEs to access credit.

Recommendation to construction SMEs

SMEs should be informed that they should provide the age, and current position in the organization of the person applying for the credit. Furthermore, they should provide the tax number and the location of the business in order for them to obtain full credit they apply for. However, it is worth indicating that SMEs should also be aware of the requirements that the financial institutions will request them to submit as they apply for credit.

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Identifying factors of risk management for the construction industry

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Abstract

Delays and cost overruns are recurrent in construction projects. Risk management (RM) has been developed to curtain risks associated with construction projects. However, there is no consensus of what factors should constitute RM for construction projects. Therefore, this paper scrutinises preceding studies on the theme of RM and establish core risk management factors (RMFs) that are indispensable to make the concept valuable in the construction industry (CI). A literature search related to RM was conducted in order to identify common RMF. It was indicated that there is still misunderstanding and disagreement over the factors that should constitute RM in construction. However, the RMFs of organisational environment, defining objectives, resource requirement, risk measurement, risk identification, risk assessment, risk response and action planning, communication, monitoring, review and continuous improvement dominate the literature. Identifying RMF that can effortlessly be understood and implemented will contribute to ameliorating the current RM status and boosting the body of knowledge.

Keywords: Contraction; factors;model; risk management effectiveness

1. Introduction

The construction industry (CI) is one of the largest employers globally. A report released by the Organization for Economic Co-operation and Development [1] indicated that the CI employs approximately 7% of the global work force or 180 million people and it is predicted to account for approximately 13% of the Global Domestic Product (GDP) by 2020. The CI is visibly a significant sector of most economies including. Because of the industry's economic significance, and the need to ameliorate the image of the CI tarnished by the high rate of project failure, many organizations have focused on RM effectiveness in the CI. References [2]; [3] supported this statement by indicating that RM improvement in construction has lately become a precedence and as a result has attracted industry-wide attention. However, improving RM effectiveness in the CI has also proved to be somewhat challenging partially owing to the industry's multifaceted nature. Regardless of the multifaceted nature of the industry, RM effectiveness improvement remains a critical concern and its importance has been illustrated in several studies [3]; [4]; [5]; [6];. The need for improving the performance of RM in the CI has been acknowledged and thus numerous ways of improving RM performance have been proposed. Among these proposals are continual improvement of RM systems [7], commitment of the board and senior management [8]; [9], share understanding and approach to RM across department (Beasley et al., 2010), use of RM techniques and tools [10], and have a RM information system [12]; [9].

However, RM and principally the uncertainty around factors of RM have been identified as being the reason of lack of RM implementation among construction firms and consequently the leading reason for delays and cost overruns observed in construction projects [13]; [14]; [15]; [16]. There is also a common consent on the fact that RMFs can influence or have an impact on construction project outcome [17]; [18]; [19]. However there is no unanimity on the factors that should constitute RM and how useful these factors can be in order to improve RM and consequently project

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performance. A review of literature indicated dissimilar definitions [20]; [21]; [22]; [23]. Consequently, it may be inferred that the disagreement on these issues could have been the reason partly for not using comprehensively the concept to improve RM performance in the CI.

A review of recent literature on the theme of RM was conducted and as a consequence, it was deduced that RM can be measured and used as a performance indicator. Factors of RM have also been identified in order to operationalize in a practical and useful way the concept of RM.

2. Literature review

Risk management status of the South African construction industry

Regardless of the initiatives deployed by the SA government to improve project management and quality performance, project overruns continue to occur in SA [24]; for example, the Gautrain project which was only ready two years after its baseline completion date and cost R14 billion over budget [25]. A further example is an R2.5 billion contract for a multi-product pipeline between Durban and Gauteng for Transnet was estimated to cost R23.4 billion and the completion date was almost 3 years late [26]. The continuing ineffective project RM of the CI in the form of cost and time overruns, poor quality achievement, project not meeting technical requirement, project not achieving user/client satisfaction, provided the catalyst for a new approach to RM in the form of consolidated construction RM and regulatory compliance legislation such as the Construction Regulations of 2003. This legislative framework required new multi-stakeholder interventions [27]. However, reference [28] indicated that there was a very little commitment to conforming to basic requirements, let alone promoting a culture of RM. Contractors could hardly maintain their RM tools and equipment and regarded RMI as costly activities. Improvement of the standard of RM performance of construction SMEs could inevitably be helped by continuous monitoring and review of their RM performance. Furthermore, reference [29] postulated that in SA, RM was also not widely used in the engineering and construction environment, and there was lack of actual adoption and implementation of RM practices. In order to overcome project failures [30] established that project success is highly dependent upon the implementation of RM practices. Reference [31] described it as one of the most capable areas and critical procedures that help to complete projects successfully. Additionally, reference [32] stated that the implementation of RM is closely aligned with overall project performance. Despite of the noted benefits of RM, cost and time overruns poor quality of work and, clients not satisfied, continue to occur on construction projects. The poor project performance highlight the need to determine RM practices those construction enterprises can use to improve their project performance. Furthermore, the plethora of studies lack consensus of the RM practices to be used by construction enterprises to improve their project performance.

Why risk management?

The reason RM is worth considering or pursuing for project performance improvement, is improved RM effectiveness has been attributed to an improvement in the RM culture of organisations in many studies including that of [3]; [4]; [5]; [33]. A better project performance has been associated with a positive RM culture dominating within an organisation concerned and indeed the industry [34]; [35]. The prevailing culture is thus very important in so far as the enhancement of construction project performance is concerned. It is because of this observation that [6] rightly argue that it seems that attempts to improve the project failures' record will not be fully realised until the RM culture is enhanced.

Consequently, it not astonishing that an effective RM is acknowledged to be a critical element of attaining and maintaining satisfactory standards of project performance [3]. It is also for this reason that reference [1] contends that it is not enough for instance to provide safe equipment, systems and procedures if the culture is not conducive to healthy and safe working. Most project failures in construction attest to the foregoing. For example "ineffective risk management" was identified as a factor leading to poor project performance by reference [36]; [37]; [38] and recently, a study conducted by reference [24] mentioned relational risk management (RRM) as one of the leading reason of project failure in construction as they argued that construction projects are usually 'people' intensive hence human nature, cultures and personalities are key variables to consider when discussing construction risk. RRM is embedded in formal and informal communication channels in the project where the cultures' of the participating organisations plays an integral role [39]. This statement is supported by reference [40] who indicated that sharing of mutual objectives, adopting a no-blame culture and aiming for continuous improvement will result in increased project success. To illustrate how other industries regard RRM, reference [39] observed that the High Reliability Organisations (HRO's) such as the Oil and Gas, Air traffic control system, naval aircraft carriers and Nuclear power operations, where serious hazards are constantly present, operating organisations and their regulators pay considerable attention

 DOI 10.3311/CCC2018-070

to risk assessment and management. They noted that these assessments are mainly on leading indicators focusing on safety climate which is a measure or determinant of the prevailing culture, because as stated earlier most of these industries have realised the importance of risk management for better project handling [3].

Furthermore, risk management at organisation level influences the deployment and effectiveness of the risk management resources, policies, practices and procedures [41]. Traditionally, attempts to improve workplace risk management concentrated on technical issues and individual human failures. However, from investigations that have been conducted in the past, the importance of risk management has been highlighted. For example, reference [42] on the investigation into the situation of British Petroleum (BP) Oil Spill in Gulf of Mexico, stated that a change in the way management approaches unpredicted events was required throughout the organisation and also at project level. Likewise, reference [43] study concluded on the Millennium Dome in south East London that it is essential to create an atmosphere in which approach and understanding of risk management is shared as the number one priority.

It has become obvious that organisations' exposure to uncertainty and risk does not merely stem from 'human errors', chance, environmental factors or technological failures alone. Rather, it is the ingrained organisational policies and standards which have constantly been shown to be at the centre of the catastrophe [1]. It is the prevailing culture in an organisation and that is the reason why RM has become important.

What is risk management?

RM denotes a coordinated set of activities and procedures that is employed to direct an organisation and to control possible events that may prevent projects from achieving established objectives [44]. RM is further defined in ISO 31000 as the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to reduce, monitor, and control the possibility and/or impact of unfortunate events [45]. RM, therefore, informs project team members on how they could manage risk, what resources are required and the cost to manage these risks [27]; [5]. This definition is also summed up by 'the way organisations anticipate on potential threats to projects' [6]; [46]; [4].

It is essential to note that there is always some form of procedure that an organisation follows to protect itself against unwanted events. The only thing is that the RM approach and methods employed to manage risks may vary among organisations. Reference [41] indicated that organisational RM exists on a continuum and that organisations can either have a good or poor RM performance. Project RM can also be referred to as the subset of an organisation's enterprise RM plan [47]; [48]. Reference [49] opined to that the necessity to manage risk in construction is continuously growing owing to various reasons which include but not limited to the intricacy, competition, size, politico-economic challenge, client-consumer requirements. Hence, the operationalization of RM in the CI cannot be overlooked. However, for RM to be operationalized, it is pivotal to know what influence it.

Factors of risk management

Confusion has reigned around what should constitute RM, partially owing to the multitude of terms that have been employed to designate the activities undertaken under RM. Some studies have referred to the parts which form, shape or make up risk management as indicators [50]; [51], factors [22]; [20]; [21]; [52]; [23], elements [53]; 54]; [6] and attributes [55]; [56] of enhanced risk management. Thus, it is important to know what these terms mean to lessen partially the confusion. The Cambridge Advanced Learner's Dictionary [57] defines the identified terms as follows:

- *Indicator (noun)*: something that shows what a situation is like.
- *Factor (noun):* A fact or situation which influences the result of something.
- *Element (noun):* A part of something, it can be referred to as what makes up something.
- *Attribute(s) (noun):* A quality or characteristic that someone or something has.

An examination of the above terms indicates that the term 'factor' refers to a fact or situation that will contribute to a result. Hence referring to risk management, this term would denote an influence that has a bearing on the outcome of the project. In other words, without the factor it is impossible to achieve the established project objectives.

An 'indicator' is described as something that shows what a situation is like or something that indicates the level of a result. Therefore with reference to risk management, this could be certain exhibits that could be observed or measured to tell the level of improvement of risk management.

The terms 'attribute' refers to the description of a quality or *characteristic that someone or something has.* Consequently, with reference to risk management this would refer to the quality or the particularity of an activity.

This study sought to establish the factors of risk management. Having scrutinised the terms that have been employed in other studies, and also based on the definition of RM, which is the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize, monitor, and control the

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probability and/or impact of unfortunate events [45]. Risk management can therefore be said to be composed of risk identification and assessment, risk prioritisation, and application of resources to reduce the impact of unwanted events [4]; [5].These are the aspects that can be referred to as the elements of RM generally. Reference [6] correctly refers to three of these, namely; risk assessment, risk response and monitoring as elements of risk management. From the definition, an element is a part of something. These elements in turn influence or contribute to project risk management effectiveness.

As for the terms that would refer to aspects that constitute risk management and influence project outcome, the term 'factor' is more appropriate as it denotes a fact or situation which influences the result of something.

The argument in this study is that it is much more beneficial, proactive and feasible to operationalize the concept of risk management by establishing the factors of risk management that contribute or influence performance of construction projects. Having established these then, efforts can be directed at improving and monitoring these factors. The task then is to identify these factors that are key to risk management and thus be used as influencers of project performance.

Identifying factors of risk management

This section identifies factors of RM that have been said to influence project performance without regard to the term that it was called but rather focus on its active description. The various factors that have been identified are outlined in Table 1.

In a survey conducted by reference [22] established four core RM elements influencing project success namely RM foundations, risk identification and assessment, risk measurement and reporting, and risk mitigation and management. According to the author, each of these elements should be developed and connected so as to work as an integrated whole. Each of these elements comprises of sub-elements as follows:

- The sub-elements of RM foundations were: senior management and board participation, governance structure, resource allocation, culture principles and values, risk management framework and policies, linkage to strategy, performance measurement, and organisational learning.
- The sub-elements of risk identification and assessment were: top-down assessments, Barriers to strategic and financial goals, Executive team CSAs, Bottom-up assessments, barriers to business, customer, and product goals, business unit CSAs, functional unit CSAs, Independent assessments, Internal and external audit, Regulators, Customers and other stakeholders.
- The sub-elements of risk measurement and reporting were: RM dashboard, Earnings volatility, Key risk metrics, Policy compliance, Real-time event escalation, Drill-down capabilities, Scenario analysis, Historical, Managerial, Simulation-based, Disclosure, Board reporting and External reporting.
- The sub-elements of risk mitigation and management were: policy enforcement, risk based pricing, and growth strategies, contingency planning and testing and Event and crisis management.

Reference [58] developed a framework to evaluate the effectiveness of monitoring and evaluation function in attaining project success in Kenya. They found four main factors which were referred to as the best project management practices. They include: managing communications; managing Stakeholders; motivating; and knowledge Transfer.

Reference [52] developed a framework to assist managers to manage various risks associated with their projects in Ethiopia. They found out that, personally focused cultural values, such as openness to change, rather than socially focused cultural values, such as self-transcendence was significant to project team performance. They further found that cultural values to have a strong relationship with two out of three dimensions of Project Team Success, namely, project team learning and development, as well as project team working spirit, when compared to project team leadership.

Reference [23] developed a framework to study the influence of portfolio RM on project success in Kenya. The study highlighted the interrelationship of the elements and how they impacted on the outcome of the project. The study was validated by respondents who were involved in project implementation at various levels. Four factors were measured using fourteen indicators. It was revealed that understanding the interdependencies between projects and their risks allows the manager to use synergies between projects thus the study concludes that risk management skills had a positive impact on project success in Kenya.

They established that risk management skills influence project success indirectly through risk identification, risk prevention, and risk monitoring. The four factors that influenced project outcome were: risk management skills; risk identification; risk prevention; and risk monitoring.

Reference [20] developed a framework of risk management to measure project

RM process for contractors with statement indicators linked to numerical scores. The overall project of the study was to ascertain the extent to which the current project RM practices are used by constructors in Malawi. They identified ten RM practices that have been discussed consistently in reports concerning RM in construction namely; risk identification; risk analysis; systems risk approach; risk exposure; risk prioritization; risk response; risk contingency planning; Risk monitoring; risk continuous assessment and the application of total quality management tools. It was found that contractors, in general, were characterised by a low implementation of the various required steps for the project RM process. They further found that most of the variables under project RM process were positively and significantly related to progression in size and experience of contractors. The study also revealed that when the risk management practices were implemented, the company achieved financial benefit in reducing lost time and employee compensation expenses.

Reference [21] developed a framework to examine the practice employed for health and safety risk assessment, communication and control at construction sites in Tanzania with a view to developing preconditions necessary to improve health and safety risk situations in construction sites. The main argument presented in the framework is that the process of risk assessment and communication is a social construction influenced by four main elements/factors that can enhance the risk management process on construction sites. These elements are the institutional system, organisational system, individual System and work environment system. Furthermore, each system had sub-elements:

- The sub-elements for institutional system were: policies/regulations and control mechanism;
- The sub-elements for organisational system were: Policies on H&S, Management style, and resource allocations
- The sub-elements for the individual system were: Perception/altitude, Experience, Education, Power relation and trust.
- The sub-elements for work environment system were: Working tools/methods/location, Work teams, working procedure and Physical space

Likewise reference [59] developed a framework to propose the key success factors, which when implemented effectively will enhance the control procedures in an organisation. The authors pointed out that Project control mainly depends on field data for assessing, analysing and corrective actions. So, quality and quick access to field data are important. This would be best possible when the team works in co-ordination with site management. He established seven fundamental factors for project control: develop the project plan, establish the project benchmarks, monitor the project performance, identify performance deviations, Evaluate corrective options, make adjustments as needed, and document, report, and evaluate results.

However, the above factors and sub factors are too abstract and make measurement of these equally difficult as the overall RMFs. The synthesized surveys were from United Kingdom, Australia, America, South Africa, Kenya, Ethiopia, Singapore, China, and Thailand.

Table 1. Factors of risk management

Factors	**Source**
Organisational environment	Phoya (2012)
Defining objectives	Papke-Shields et al. (2010)
Resource requirement	Phoya (2012)
Risk measurement	Oztas & Okmen (2004**)**
Risk identification	Oztas & Okmen (2004**)**; Matalanga & karanja (2014); Matalanga & karanja (2014); Papke-Shields et al. (2010)
Risk assessment	Oztas & Okmen (2004**)**; Papke-Shields et al. (2010)
Risk response & action planning	Mahendra et al., (2013); Papke-Shields et al. (2010)
Communication	Kamau & Mohamed (2015)
Monitoring, review and continuous improvement	Matalanga & karanja (2014); Mahendra et al. (2013); Papke-Shields et al. (2010)

Identified risk management factors and they measures

A list of RMFs which are deemed to influence project performance has been drawn based on the above analyse. This list was drawn based on the similarity of the factors from the studies reviewed disregarding the different terms used. In addition to the factors, 43 measures were also identified and were categorised in 9 factors. The nine core factors of risk management which influence project performance include, (1) organisational environment (2) defining objectives (3) resource requirement (4) risk measurement (5) risk identification (6) risk assessment (7) risk response and action planning (8) communication and (9) monitoring, review and continuous improvement. These have been found to be common to all studies. These factors together with their measures were therefore used to propose the conceptual model of risk management. Table 2 below depicts the identified factor with their measures.

Table 2. Measures of factors of risk management

Factors	Measures
Organisational environment	1.Identifies and assess the internal environmental factors 2.Identifies and assess the external environment factors 3.Understands the internal environment, which concerns all factors influencing the manner in which firms manage risks 4.Uses the organisation business system to document the internal & external environment
Defining objectives	1.Defines the organisational focus 2.Determine the positioning of the risk management function within the organisation 3. Define the objectives and methodology of the risk management process. 4. Determine how the effectiveness of the risk management process can be assessed 5. Determine how the effectiveness of the risk management process can be assessed. 6. Determine how the responsibility & accountability for the risk management process can be defined
Resource requirement	1. Considers the personnel availability and know-how. 2. Considers time requirement in terms of scheduling risk meetings/workshops. 3. Considers information system requirements in identifying risks, implementing controls and follow-up activities. 4. Considers risk communication mechanism.
Risk measurement	1.Define the risk measurement to be used 2. Defines the risk materiality 3.Define the risk timeframe applicable to risk impact and risk probability 4. Clarify the risk terminology 5. Determines the level of acceptable risk.
Risk identification	1. Develop risk information database 2. Conduct present and future risk identification 3. Identify how and why risk arise 4. Use physical inspection to identify the risk
Risk assessment	1. Determine the risk cause, risk duration, risk volatility 2. Determine the probability of the risk occurring, the impact, classification consistency. 3. Establish the risk profile. 4. Assess the risk by quantitative analysis methods 5. Assess the risk by qualitative analysis methods
Risk response and action planning	1. Identify risk treatment options by avoiding risk 2. identify risk treatment options by mitigating risk 3. Identify risk treatment options by retaining risk 4. Identify risk treatment options by transferring risk 5.Define actions to counter the identified project risk 6. Prepare an implement risk action plan
Communication	1. Establish a communication process for interactive (two-way) consultation with stakeholders. 2 Establish a reporting structure, whereby risk information derived from the risk management process, is communicated timeously to appropriate parties. 3. Establish a crisis communication strategy facilitating immediate information exchange 4. Develop a communication evaluation mechanism
Monitoring, review and continuous improvement	1. Assign responsibility for monitoring and review actions. 2. Identify and select monitoring and review techniques 3. Assess control effectiveness, measured in terms of meeting departmental, organisational objectives. 4. Do control enhancement by revising ineffective controls identified 5. Report the new results from monitoring and review activities.

From the insight of the above measures it can be inferred that RM can be characterised at all levels of the organisation or industry. The insight can expose the way things are done concerning the identified factors [59]; [60]. Furthermore, it is possible to build a picture of an organisation and also understand where opportunities for improvement lie. Some researchers such as [13]; [14]; [15]; [16] proposed a plan that can be followed at organisational and industry level in order to improve RM effectiveness as follows:(1) Assessing the organisation current level of RM (2) Developing a plan to move to the next level (3) Implement the plan (4) Monitor the implementation of the plan (5) Re-assess the level of RM for further actions.

It is easier and practical to view the identified factors of 1) organisational environment (2) defining objectives (3) resource requirement (4) risk measurement (5) risk identification (6) risk assessment (7) risk response and action planning (8) communication and (9) monitoring, review and continuous improvement that can be used to improve

RM effectiveness. The process of improvement can therefore follow the following stages: (1) Assess the model (2) Develop methods to enhance the model (3) Implement methods (4) Assess the model (5) Compare with baseline levels to indicate movement (6) Consult and disseminate information (7) Develop methods to enhance the model and (8) Repeat process 3-8.

It is importance to note that implementing the model has to take cognisance of the external environment factors that can similarly have an influence on project performance. This statement was supported by [21] who indicated that RM at organisation level does not operate in a vacuum; rather it affects and is affected by the external environment.

3. Methodology

The work methodology included a literature search. The study was conducted with reference to preceding literature to risk management. This is because RM has attracted much worldwide attention in recent years [40]. The literature search was based on systematic keyword combination search online databases and by consulting Journals and conference proceedings. Database engines search included; Science Direct, Taylor and Francis Online, Ebscohost, and Emerald. The authors used advanced search for the database engines and basic search for Google. The keywords and phrases used for the data search were;" risk management", "risk management influence on project outcome in construction", and "risk management effectiveness measures". The basic search used was "factors of risk management in construction". Articles/reports consulted were peer-reviewed articles, written in English, they indicated the objective of the study; the method employed, and report the results to the objective of this literature and a conclusion.

3. Discussion and conclusion

This study sought to identify RMFs that are indispensable to make the notion valuable in the CI. The reason why RM should be taken into consideration in the CI has been outlined. It was further noticed that RM effectiveness improvement is improbable without the improvement or change in the way risk is approached.

The factors of risk management were identified. It was observed that the reason RMFs has not been employed to the full has been undoubtedly to the various terms that have been utilised to characterise RM and consequently the resultant confusion. It was also revealed that it is beneficial to consider those factors that influence project performance and subsequently measure their metrics. This has been said to be more proactive and practical.

The core RMFs that were revealed to be common in literature included organisational environment, defining objectives, resource requirement, risk measurement, risk identification, risk assessment, risk response and action planning, communication, monitoring, review and continuous improvement which have collectively been referred to as RMFs for project performance improvement.

It was further evinced that the identified factors can be employed to both plan for and measure RM effectiveness. The present study has thus contributed to the efforts aimed at improving RM effectiveness in the CI by demonstrating how RM can be operationalized practically.

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Identifying Infrastructure project uncertainties during project initiation using system thinking

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Abstract

This paper describes a system thinking conceptual framework which will be utilized in identifying uncertainties in infrastructure project during initiation stage deduced from literature review. It forms part of an ongoing PhD research project whose aim is to improve costing in infrastructure project to accommodate uncertainties. The paper concludes that system thinking approaches will enable key stakeholders in infrastructure project to identify and manage uncertainties that will impact on project goals adversely.

Keywords*:* Infrastructure project, System thinking, Uncertainty/Risk &Conceptual Framework Design*;*

1. Introduction

Traditionally, construction project professionals tend to focus more on risk and its impact neglecting the effective management of uncertainties. A lot of risks emerges from uncertainties which were not properly identified at the early stage of the project. Utilization of non-systemic (Traditional) approaches in risk management is widely practiced by construction project professionals which is a deterministic technique based on experience and laid down format[1](Atkinson, 1999). Due to the complexity and dynamic nature of infrastructure projects a holistic approach which integrates system thinking by gaining understanding of the functions, relations between them and environmental influences is needed for effective uncertainty management. System thinking approaches sees a construction project as a whole system by understanding and examining the relationship, interactions between the parts (stages and processes) that comprise the entirety.

Uncertainty management in the construction industry is now given an utmost attention for the effective construction project management. Sources of uncertainties within the infrastructure project emanates from various stages which was not adequately planned against during project conceptual stage. Traditional construction project management practices does not take cognizance of the fundamental sources of uncertainties. Holistic approach is quite needed to explore the sources of uncertainties within the infrastructure project so as to generate a robust uncertainty management for effective construction project management [2](Atkinson et al., 2006). The impact of ineffective uncertainty management can be very devastating in achieving the objectives of infrastructure project. It is advisable to detect or identify early the devastating uncertainties during the project initiation stage prior to progression. This will assist the key

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stakeholders within the construction project to make vital decision. A lots of risk emerges from uncertainties during the construction project lifecycle which wasn't properly identified or known about during the high level risk identification phase (Initiation stage).This risk can spread in an unpredictable manners sometimes lead to catastrophic ends. The dynamic and complex nature of infrastructure project makes it more susceptible to unforeseen events such as uncertainties. It has been discovered that overemphasis on operational control and lack of flexibility in the traditional project management is not sufficient enough for effective achievement of project objectives.The management of boundaries relations and operational change are the key success factors in effective delivery of project objectives which system thinking approach provides[3](Kapsali, 2011).Sources of uncertainties within the infrastructure projects are wide ranging and the traditional approach does not address it adequately. Flexibility and tolerance to vagueness are more paramount at the moment to manage the complex nature of infrastructure project. Extensive efforts are required which should inculcate effort such as organizational capability (Culture and learning approach [4](Atkinson et al., 2006).Infrastructure project is dynamic and complex thus involving significant amount of risks.The duration and scope which involve many parties in dynamic relationships with a multitude of interdependencies makes it more susceptible to risks which can propagate through numerous pathways in an unpredictable way[5](Loosemore, 2015).It is known that risk is embedded into any commercial organization's profit structure which is a basic feature of free enterprise system [6](Akintoye and MacLeod, 1997).Identifying and analyzing the relationship between the proposed infrastructure project and the embedded risk in the organization poses a great challenge for the key stakeholders. System thinking tends to give a closer analysis by understanding the interrelationships, interconnectedness between the process and stages within the projects in order to achieve or deliver the objectives. It has the ability to represent and assess dynamic complexity such as an infrastructure project [7](Sterman, 2000).It is advisable to identify early enough the potential uncertainties that might impact on the objectives of carrying out an infrastructure project during initiation stage. This paper intend to demonstrate that system thinking approach possess the adequate framework to identify infrastructure project uncertainties during initiation stage.

2.0 Literature Review

2.1 System thinking

The utilization is thought to facilitate complex decision making by various experts in the field [8](Lezak and Thibodeau, 2016).In infrastructure projects where activities are carried out in a sequential and dynamic order the utilization of system thinking will be quite useful. This will assist greatly in understanding the complexity posed in executing infrastructure projects. Complex systems such as Infrastructure project are marked by high level of uncertainty, ambiguity as well as emergence [9](Jaradat, 2016).It is paramount at this era to have a holistic thinking paradigm that creates new charter and opportunities to think differently on how complex system such as infrastructure project can be executed effectively [10] (Jaradat, 2016).

The uniqueness, complexity and uncertainty involved in executing activities in infrastructure projects make control more cumbersome thus deviation from plans becomes more probable [11](Sydow and Staber, 2002).This prompt the need for change management which is generally linear in approach following some predetermined formalized communication model. In this type of reductionist approach lacks flexibility thus creating obstacle in producing an explanatory and predictive framework for managing infrastructure project [12] (Müller, 2003).During executing a project, task becomes uncertain resulting to change unpredictability and this requires creativity. The project control and management team of infrastructure project needs creativity to tackle this non-linear and evolutionary phases [13](Smyth and Morris, 2007).According to [14] John (2007) system thinking can be utilized to gain an understanding of individual, collective behaviour, human as well as technical alike which cannot be derived from standalone analysis. This will be achieved through synthetic and integrative thinking approaches. It has been researched that system thinking can complement the conventional management strategy utilized in managing infrastructure project by suggesting different levels of analysis and synthesis for problems [15](John, 2007).Infrastructure project is quite susceptible to unforeseen complex changes which tend to make the initial plan move inordinately to a catastrophic level if adequate remedial measures is not put in place. In order to manage and plan against this issue, it requires flexibility in approach which system thinking provides.It can provide a conceptualize framework which utilizes different tools, theories and strategies to build a holistic, contingent outlook and practices [16](Carmen, 2009).It is pertinent during Infrastructure Project initiation to identify uncertainties that might impact adversely on the project objectives before a decision is made by the key stakeholder. It is generally faced with limited information about the project to be carried out and crucial decision is necessary before final initiation. This stage is carried out with highest level of uncertainties on the project with lowest level of precise information as well.

2.2 Uncertainty

It can be simply explained as lack of certainty involving variability or ambiguity. The management of uncertainty deals with managing perceived threats and opportunities as well as the risks implications. It also involve the managing of various sources which lead to risk, threat and opportunity[17](Chapman, 2003).This paper will solely deal with the identification of main sources and factors that generate uncertainties in an infrastructure project early enough during project initiation stage using system thinking approaches. In order to clearly illustrate the approaches utilized in this paper a clear distinction needs to be made between uncertainty and risk in infrastructure project.Risk can be described or explained as the exposure to uncertainties that will have adverse effects on project objectives. A reliable strategy known as risk management is utilized in reducing and controlling risks [18](Tam, 2012).The traditional construction project management team focuses too much in managing, reducing and controlling risk already identified previously with similar project without paying more attention on uncertainties within the organization itself which might impact adversely on the project objectives. The general practice involved, is having a generic risk management template for managing and controlling risk without critiquing the interconnectivity and interconnectedness of activities within the project and how it impact on the organization(operating environment) strategic objectives. Construction projects are confronted with strategic issues which may have impact on the performance in the long run. It is paramount to balance the key stakeholders' objectives with adequate risk management strategies [19](Abednego and Ogunlana, 2006).System thinking approach will employ mainly the soft system strategy in bridging the operating environment(organization) and project objectives together so as to achieve a meaningful and purposeful deliverables. This approach will ensure a conceptual framework that equal social to technical, uncertainty and complexity as integral part of the management of tasks, planning and control [20](Saad et al., 2002).In conventional project management a hard system approach is utilized which tends toward process management [21](Phelan, 1999). It utilizes mainly hard system which focuses on process standardization in terms of constrained triangular metrics(Cost, Time and Scope) [22](Atkinson, 1999).Soft system approach will not replace the conventional method of infrastructure project management but complement it.

2.3 Infrastructure project

It is often utilized as a way of achieving organization's strategic plans directly or indirectly. This is always triggered or authorized as a result of some strategic consideration such as market demand, strategic opportunity/business need, social need, environmental consideration, customer request,techmological advancement & legal requirement [23](PMI, 2013).In infrastructure project initiation phase is where the key stakeholders expectations are aligned with project's purpose so as to give them visibility about scope and strategic objectives. Also set's the project vision and what's required by the project to accomplish. Initial scope is defined, initial financial resources commitment made as well, both internal and external stakeholder who will influence the project outcome is identified[24](PMI, 2013).At this stage,overral plans made are from expert judgments and contains lot of biases due to limited information about the project. This makes the infrastructure project prone to a lot of uncertainties which is a potential source of risks. Traditional techniques involved in achieving the initiation phase of an infrastructure project are mostly reductionist approaches and doesn't pave way for surrounding uncertainties to be adequately examined. A strategy which involves holistic, interconnectivity and interdependence approach is required to fully understand complex project like infrastructure type [25] (Stewart and Fortune, 1995).Holistic problem overview is required where situation is perceived in reality as a systems, also components relationships between system and

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external environment are well established [26](Stewart and Fortune, 1995).System thinking approaches utilizes different tools for achieving the sole objectives.
This paper will describe a conceptual framework for utilizing soft system analysis a system thinking method. It is a holistic approach applied to an infrastructure project which is viewed as a broader system with various subsystems underneath. It deals with both hard tangible information and soft complexity (People's involvement and Conflicting interest)[27](Stewart and Fortune, 1995).The findings of this paper are solely based on and derived from various existing literature reviewed for ongoing doctoral research studies. In order to fully understand this conceptual framework a system diagramming technique will be utilized to depict holistic, interdependence and interconnectivity amongst the system and subsystems involved.Rich picture concept mapping and causal diagram will be utilized for the system diagramming technique.

2.4 Rich picture
It is a graphical representation technique of soft system methodology which represents a complex situation[28] (Pain, 2012).This will be quite useful during infrastructure project initiation stage precisely during conceptual estimation phase.The conceptual and preliminary estimating phase normally takes place prior to engineering and design completion. This is when there is limited information about the infrastructure project to make a robust estimate. It is done in the schematic and budgetary section of the project initiation stage. It is generally susceptible to high level of uncertainties due to vague information available. It can be readily utilized to organize complex situations and identify underlying issues and stakeholders of a system[29] (Pain, 2012).Any tools can be used to represent a rich picture as long as it encourages discussion, interaction as well as attaining holistic understanding overview of a system by key stakeholders [30] (Pain, 2012). Infrastructure project can be well represented holistically using rich pictures during the initiation stage so as to identify potential uncertainties that might impact on project objectives. Some of the inputs for this technique will be related history and lesson learned files of similar project. This technique gives a preliminary overview of the operating environment of infrastructure project with external influences and doesn't really dig deep into the dynamics that might impact on the project objectives.Another soft system methodology is required for further analysis.

2.5 Concept Mapping
It can be simply described as the integration of qualitative and quantitative methods designed to enable a group of people to articulate and depict graphically a coherent conceptual framework or model of any issue or task of interest [31] (Trochim and McLinden, 2016).This will be quite resourceful during infrastructure project uncertainties identification. It enables multiple stakeholders within the infrastructure project to produce interpretable pictorial view of their various ideas, concepts, including how they are interrelated as well. The interrelationship between the elements within the system can be adequately depicted using concept mapping. The input directly from the rich picture can be studied to some extent using this soft system methodology. During infrastructure project initiation when high level risks, assumptions, issues and constraints etc. are being identified concept mapping approach will be effective. It can assist in providing information where potential constraints, uncertainties might spring-up from having analysed the operating environment and external influence on the project via rich picture. In order to depict the entire interconnectedness and a robust feedback loop amongst the system elements a further soft system analysis is required namely causal diagram.

2.6 Causal Diagram
A causal diagram is utilized by identifying key variables (Elements) within a complex system and indicating the causal relationships between them via a feedback loop. This constructed loop is then used to create a concise framework about a particular issue or task [32] (Lannon, 2018).Causal diagrams assist complex systems to understand the behaviour of elements within them thus creating more insight into how the subsystem behaves. The input from both the rich picture and concept map can really assist in generating a robust causal diagram of an infrastructure project. Understanding how the infrastructure project phase's works, most especially the activities within the initiation stage where limited information is available will

assist greatly in generating potential uncertainty sources and factors as well. Crucial relationship between the system and the external environment is quite essential. For instance depicting the causal effect of finances, geological conditions and political atmosphere on the project will be quite helpful in planning for proactive strategies. It can also be utilized for stakeholder analysis and their influences on the project as well. It will assist the project management team to plan accurately the communication channels.

3.0 Conceptual Framework for Infrastructure project uncertainties identification.

The conceptual framework will be depicted descriptively from the sourced literature review. It will be compared in tandem with hard system and Soft system methodology.This framework will be tested and proved when appropriate data are sourced from case study firm (Construction industry) during the PhD thesis progression. The conventional approach is of the reductionist type and does not address adequately the change and dynamics within the infrastructure project activities. Employing this conceptual framework will assist to understand the dynamics, interrelationship and interconnectedness amongst the activities as well as phases within the infrastructure project enabling the stakeholders to identify uncertainties that may impact on objectives. Employing Soft system analysis (System diagramming technique) in identification of infrastructure project uncertainties is a nascent approach which will contribute immensely to the body of knowledge. The proposed conceptual framework is depicted below in figure 1

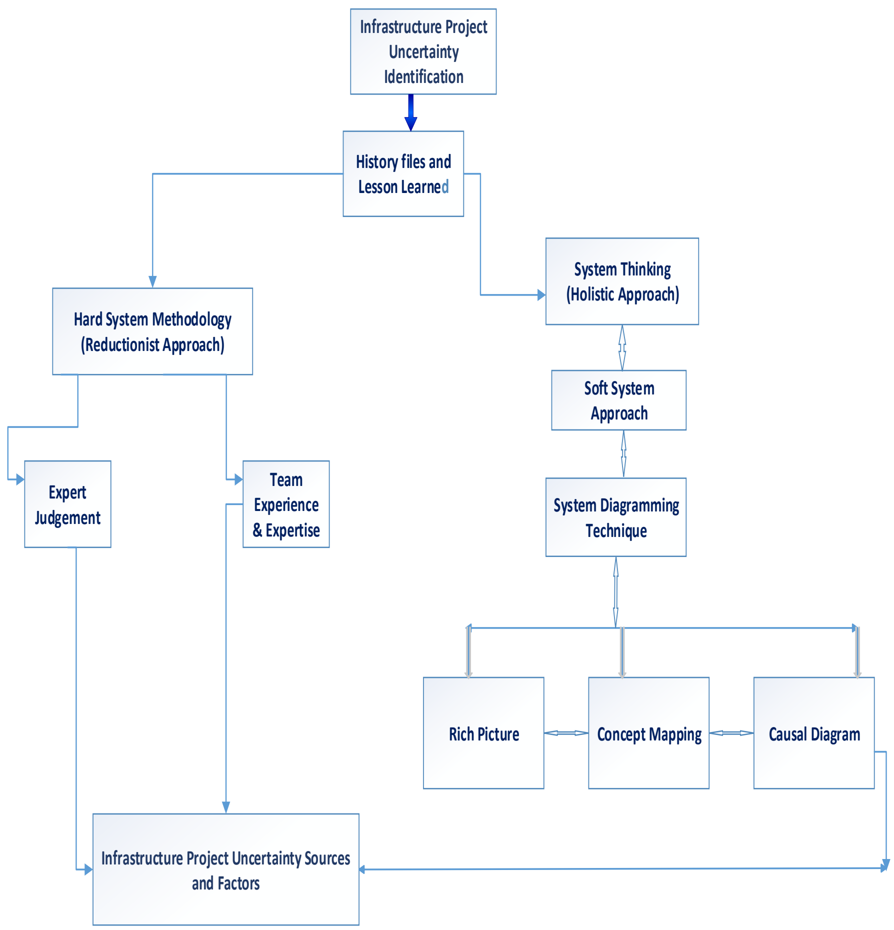

Fig.1 Conceptual framework design

4. Findings

Organizations embarking on an infrastructure project faces high risk due to the complexity involved. In order to mitigate the impacts of any uncertainties that might hinder the effective execution of the project activities a proactive and holistic approach is quite essential. This conceptual framework design utilizing system thinking described above will enable key stakeholders to identify early enough uncertainties that may impact on project objectives. These uncertainties are mainly major sources of risks which may have adverse effects on project delivery. This conceptual framework will also enable the project management team during initiation stage to be proactive enough to these major sources of risk and proffer contingency plans so as to mitigate the impact to an acceptable level prior to actual execution. This systemic approach will serve as a supplementary technique to the existing approaches.

5. Conclusion

The Infrastructure project uncertainties varies considerably depending on the nature and type of project operating environment. The above conceptual framework is applicable to mostly project executed in Europe and North America. In order to design a robust framework, statistically significant data are needed to be analysed appropriately. Due to the stage of the ongoing PhD thesis work, data are yet to be sourced so as to produce a robust work. This framework is to serve as a supplement to the traditional management approach of uncertainties and risk.

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Improvement measures for the maintenance market through the current status analysis in Korea

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Abstract

The construction market in Korea has developed through the quantitative expansion of economic development over the last decades. However, due to recent trends in the decrease in construction volume and shift of paradigm from construction of new facilities to maintenance of old facilities, the number of buildings aged over 30 years in Korea have accelerated rapidly. After the emergence of a construction trade with specialty on facility maintenance and management, policies and regulations related to the roles of a contractor specialized in facility maintenance and management in Korea was created in 1990. However, due to the uncertainty of the scope of work, there still exists conflictive viewpoints among construction stakeholders – mainly the general and specialty contractors – in the market. Furthermore, whilst the number of contractors licensed for facility maintenance and management work is too large compared to its market size, the contract amount per construction project is continuously decreasing. Therefore, this study identifies the problems related to the market structure in the Korean maintenance market. Also, this study suggests improvement measures for the Korean maintenance market and presents a structure for sustainable construction delivery in Korea.

Keywords: Facility maintenance and management, Maintenance market, Institution.

1. Introduction

1.1. Background

After the Korean construction industry has entered a phase of maturity, the paradigm of construction market is expected to shift from new construction to maintenance work related to residential renovation, urban regeneration, maintenance and resumption of Social Overhead Capital(SOC) facilities. As the number of buildings over 31 years old is expected to exceed over 33% in the year 2029 [3], the maintenance market is expected to expand in vast rapidity. Thus, it is required to devise improvement schemes of the construction industry to cope with such environmental changes preemptively.

However, in Korea, the construction projects on facility maintenance and maintenance are ordered based on the work area of general contractors and specialty contractors under the construction production system defined by law several decades ago. Due to the institutional nature of law in the Korean construction industry, a conflict structure in the market has been created among construction stakeholders in relation to the interpretation of the scope of work of the maintenance and management work and the status of participation of construction contractors. First of all, there is a controversy among the construction stakeholders – general contractors and specialty contractors engaged in all types of construction work – regarding the current construction policy on the definition of 'facility maintenance and management' that insinuates as if only those licensed and registered for specialty contract on facility maintenance and management work can participate in the emerging maintenance market. Also, the number of companies registered for

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facility maintenance and management work exceeds 5,300 in 2017, which resulted in an intense competition within the market and continuous decrease in the contract amount per construction project.

Therefore, this study proposes improvement measures for devising a rationalization plan on the maintenance market in Korea by diagnosing the issues that need to be improved through the analysis of current situation and the market analysis in the field of facility maintenance under the current construction industry system.

1.2. Scope & Methodology

This study analyzes the current issues in the Korean construction industry for rationalizing the maintenance market by performing an assessment on market concentration through HHI and CR_k index calculation, and an analysis on controversial problems among participants of construction phase in the Korean facility maintenance market.

This study is performed under a fourfold purpose. First, the background of the facility maintenance and management work, which is classified as the scope of work for one of the twenty-five specialty contractors, is analyzed. Second, the market size is examined in terms of registration status and contract performance of facility maintenance and management contractors. Third, by implementing the HHI and CR_k indexes as the market share of contractors, the structure of maintenance market and the resulting controversies among construction stakeholders – mainly the general contractors, twenty-four types of specialty contractors, and the specialty contractor registered for facility maintenance and management work – are derived. Fourth, improvement measures for the Korean maintenance market is proposed through the current status analysis.

2. Literature review

2.1. Construction Industry in Korea

Construction contractors in Korea are divided into general and specialty contractors. General contractors are those that construct facilities while performing comprehensive planning, management and coordination, whereas specialty contractors are those that perform construction work for some of the facilities in a specialized field. The current production system in the Korean construction industry has vertical division of contract work between general contractors and specialty contractors and a horizontal division of work among the specialty contractors. General contractors can engage in five types of construction work, whereas specialty contractors can engage in twenty-five types of construction work by registering in each scope work.

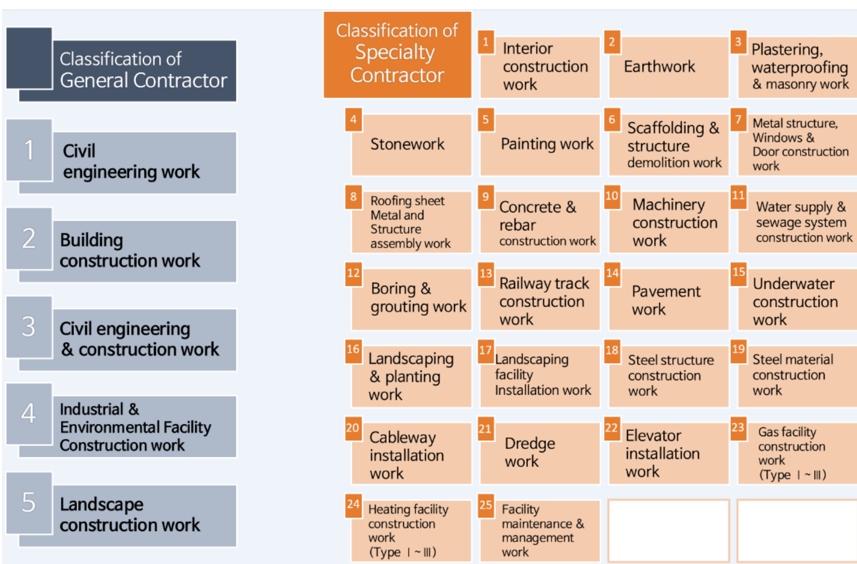

Fig. 1. Classification of construction industry in Korea

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The classification of work on facility maintenance and management was first introduced as one of the types of specialty work in 1995 to improve maintenance and safety management of major facilities and to prevent large-scaled safety accidents such as the collapse of Sungsu Bridge and Sampoong Department Store. According to the Framework Act on the Construction Industry, the scope of the facility maintenance and management work includes any construction work after the construction phase while excluding improvement, maintenance, and reinforcement works of buildings that can be performed by a single-type specialty contractor. In other terms, in a construction project where two or more specialized construction works are combined (e.g. interior construction work + painting work after construction phase), only the contractors registered for facility maintenance and management work can participate in the market. Table 1 describes the scope of work for contractors specialized and registered in all fields excluding facility maintenance and management and the contractor registered for facility maintenance and management work within the maintenance market.

Table 1. Scope of work in the Korean maintenance market

Category	Specialty contractor (except facility maintenance And management)	Facility maintenance and management
Single type construction	Possible	Impossible
Multiple type construction	Impossible	Possible

Meanwhile, the current facility maintenance and management companies are mainly engaged in simple repair and reconstruction work in the physical construction aspect rather than the maintenance and safety management expertise. Furthermore, considering the market size and share, the maintenance market has been excessively concentrated and overheated. Currently, there are over 5,300 facility maintenance and management companies registered for the specialized work, accounting for about 8% of the total specialty contractors. Considering the total share within the construction industry, an excessive degree of registration among contractors resulted in a competitive market place. Therefore, quantitatively measuring the market concentration through calculating the major indexes such as Herfindahl-Hirschman Index (HHI) and Concentration Ratio of multiple firms (CR_k) is essential for diagnosing the problems in need of improvement in the maintenance market.

2.2. Herfindahl-Hirschman Index (HHI)

The Herfindahl-Hirschman Index (HHI) is a commonly accepted measure representative of the market share in a particular market, calculated as the weighted sum of market share of each firm. HHI has the advantage of increasing the index value as the share of the higher company increases, because it gives a higher weight to the higher company than the lower company and has the advantage of accurately measuring the concentration of the market accurately. The HHI index is calculated according to Equation (1):

$$\mathrm{HHI} = \sum_{i=1}^{N} {S_i}^2 \quad (1)$$

2.3. Concentration Ratio of the above business k (CR_k)

Concentration Ratio of the above business k (CR_k) is the ratio of the top *k* number of firms occupying the share in a market, which is calculated as the cumulative market share of the first *k* number of firms. Although the randomness of researchers can affect in selecting the firms occupying the *k*th rankings and the degree of inequality in the market cannot be known, CR_k is a useful indicator for determining the degree of competition among firms in a limited market. The CR_k index is calculated according to Equation (2):

$$\mathrm{CR}_k = \sum_{i=1}^{K} S_i \quad (2)$$

The calculation results of the two indexes can be interpreted as described on Table 2.

Table 2. Interpretation of Indexes

Type	CR_k	HHI	Implementation
No concentration	0%	0.0000 ~ 0.0500	Perfect competition
Low concentration	1% ~ 40%	0.0501 ~ 0.1000	Ranges from perfect competition to an oligopoly
Medium concentration	41% ~ 70%	0.1001 ~ 0.2000	Likely an oligopoly
High concentration	71% ~ 99%	0.2001 ~ 0.9000	Ranges from an oligopoly to a monopoly
Total concentration	100%	0.9001 ~ 1.0000	Total monopoly

2.4. Previous studies

The study on the classification of construction industry in Korea is as follows. According to the study of Lee et al. [3], Korea is expected that that the maintenance market will account for more than 40% of the entire construction market after 2020, as the maintenance demand for existing facilities surges. Lee et al. [4] analyzed the problems caused by the construction industry in Korea and presented cases of the of U.S. construction market structure.

Jeong et al. and Lim, et al. [5, 6, 9] analyzes the overall problems of the classification of construction industry in Korea and suggests ways to revise the classification. However, there was no analysis of facility maintenance and management work in the study of Jeong. Korea Institute of Construction Engineering and Management [7] pointed out that the structure of the domestic construction market does not cope with the global standard and thus lacks competitiveness in the global market. The institute suggests improvement schemes to improve competitiveness of the Korean construction industry.

Although there exist qualitative studies on the problem and maintenance market in Korea, there have been no studies that quantitatively analyzed the maintenance market and suggested improvement measures on the market structure.

3. Market status analysis of facility maintenance and management

3.1. Number of license

As of 2016, the total number of specialty contractor companies in Korea is 62,000, of which 5,200 are facility maintenance and management companies. According to Table 1, facility maintenance and management companies accounted for 2.2% of total specialty contractor companies in 1999 but increased 3.8 times in 2016 to 8.3%. In spite of the fact that specialty contractors are classified into 25 types of work, facility maintenance and management companies account for 8.3% of total specialty contractors and reached that increase within a short period of time.

Table 3. Number of license

unit: number

	1999	2000	2001	•••	2013	2014	2015	2016
Specialty contractors (A)	55,217	60,779	67,703	•••	64,654	62,918	62,715	62,444
Facility maintenance and management (B)	1,224	1,604	1,982	•••	4,496	4,688	4,893	5,159
(C) (=B/A)	2.2%	2.6%	2.9%	•••	7.0%	7.5%	7.8%	8.3%

The number of facility maintenance and management registrations analyzed in this study is a number including companies that are registered in multiple works (e.g. Civil engineering work (classified as general contractor) + Facility maintenance and management work (classified as specialty contractor)). In general, one specialty contractor company can acquire two or more licenses.

3.2. Number of works

Table 4 shows the total number of works for specialty contractors registered in all twenty-five types of work and those for contractors classified as a 'facility maintenance and management company'. The number of works contracted by facility maintenance and management companies has increased by 12.7 times, from 5,696 in 1999 to 72,182 in 2016. During the same period, the number of specialty contractor companies increased only about 2 times.

The proportion of construction projects contracted by facility maintenance and management companies among all companies registered for specialty work accounts for 11% in 2016, a leap from 1.7% in 1999. This means that as the domestic construction market matures, the maintenance business has been growing rapidly.

Table 4. Number of works

unit: number

	1999	2000	2001	•••	2013	2014	2015	2016
Specialty contractors (A)	328,333	401,407	477,646	•••	546,499	531,619	622,814	656,123
Facility maintenance and management (B)	5,696	13,877	20,806	•••	62,750	62,632	68,395	72,182
(C) (=B/A)	1.7%	3.5%	4.4%	•••	11.5%	11.8%	11.0%	11.0%

3.3. Contract amount

Table 5 shows the total contract amount for specialty contractors registered in all twenty-five types of work and those for contractors classified as a 'facility maintenance and management company'. Compared to the total contract amount for all specialty contractors, the amount of facility maintenance and management contracts increased by 8.2 times from 511 million dollars in 1999 to 4,187 million dollars in 2016. During the same period, the total amount for all specialty contractors excluding those on the maintenance field increased only about 2.8 times.

Table 5. Contract amount

unit: million dollars

	1999	2000	2001	•••	2013	2014	2015	2016
Specialty contractors (A)	32,082	34,609	39,248	•••	73,300	73,138	82,275	90,105
Facility maintenance and management (B)	511	675	966	•••	3,266	3,191	3,839	4,187
(C) (=B/A)	1.6%	2.0%	2.5%	•••	4.5%	4.4%	4.7%	4.7%

As a result of comparing the maintenance market size with the specialty contractor and the facility maintenance and management, the maintenance market shows that the number of construction works, the number of registrations, and the amount of contract are higher than those of specialty contractor companies in total.

The analysis above verified that the Korean construction market gradually grew mainly in the maintenance market after entering into maturity pace in the late 1990s.

3.4. Analysis of value of construction performance

The CR_k and HHI indexes were obtained through the value of construction performance in 2017 of 5,300 contractors registered for facility maintenance and management work. The top three firms have a market share of 2.09% (CR_3), while the top five facility maintenance and management companies have a market share of 3.11% (CR_5), the top 10 with a market share of 4.73% (CR_{10}), the top 50 with a market share of 12.25% (CR_{50}), and the top 100 with a share of 18.17% (CR_{100}). When analyzing the maintenance market structure, the HHI can be judged to be highly competitive with 0.0007. The analysis of the CR_k and HHI index revealed that the maintenance market is under a low concentration with high competition among construction firms registered for facility maintenance and management work.

Table 6. Facility maintenance and management market concentration

	CR_3	CR_5	CR_{10}	CR_{50}	CR_{100}	HHI
Facility maintenance and management market	2.09%	3.11%	4.73%	12.25%	18.17%	0.0007

4. Disputes with maintenance market.

4.1. Disputes over the scope of maintenance work

Recently, conflict has been arising between specialty contractors (registered for twenty-four types of work except for facility maintenance and management) and those registered for facility maintenance and management in regard to the scope of maintenance market. The current construction industry in Korea distinguishes the role of a facility maintenance and management firm as one of the specialty contractors. However, unlike other types of specialty contractors, the definition of ‘maintenance’ in a construction facility is not distinguished by specific technology corresponding to a professional field of work. The scope of work for facility maintenance and management is not limited to some specific types of work; there must be at least two work areas for a facility maintenance and management contractor to perform its work. For example, in case an owner of a commercial building wants a repair work comprehending 80% of interior construction work (classified as type No. 1 of specialty contractor) and 20% of the painting work (classified as type No. 5 of specialty contractor), the repair work can be only performed by facility maintenance and management firm (classified as type No. 25 of specialty contractor).

As mentioned above, no matter how the portion of each specialty work accounts for, the maintenance project combining two or more types of specialty works can only be done by facility maintenance and management firms. Therefore, in the case of maintenance projects being ordered, other specialty contractors cannot participate in the bid. As a result of these constraints, there inevitable rises a dispute between facility maintenance and management firms and other specialty contractors regarding an authoritative interpretation of the scope of work. The current law and policies in the construction industry allow the facility maintenance and management firms to receive more opportunity to participate in the maintenance market as a prime contractor compared to the other firms registered for specialty contractor. The construction maintenance market legally formed by law and policies serve as an impediment to the selection of a construction firm based on construction capability.

4.2. Excessive competition within the maintenance market

In the Korean maintenance market, the contract amount has increased about 2.8 times while the number of construction firms has increased about 12 times over 20 years. Competition in the Korean maintenance market has also been intensified due to the rapid increase in market share and number of companies in a short period of time.

Table 7 compares the contract amount per construction work or project between those of facility maintenance and management firms and those of other specialty contractors. The contracted amount for specialty contractors excluding those registered in facility maintenance and management work has been over 1.4 million dollars, but the amount for facility maintenance and management contractors has reached only 0.058 million dollars in 2016. Therefore, the maintenance market in Korea signals an overheat due to the competition of more than 5,300 firms.

Table 7. Contract amount per construction work

unit: million dollars

	1999	2000	2001	•••	2013	2014	2015	2016
Specialty contractors (Except facility maintenance and management work)	1.04	0.92	0.88		1.43	1.47	1.51	1.55
Facility maintenance and management work	0.090	0.049	0.046	•••	0.052	0.051	0.056	0.058

5. Improvement Measures

5.1. Shift to an autonomous maintenance market

In order to devise an improvement schemes on the Korean construction industry in general from a long-term point of view, it is necessary to plan to shift the paradigm of construction industry from a legally ordered to autonomously flowing market, thereby allowing the contractors to enter the market based on their experience and technology of the construction company. The facility maintenance and management market is no exception from this shift; the maintenance projects are being ordered to contractors based on the production system that has been defined by law several decades ago regardless of the actual scope of work. Therefore, any terms defined in law and policies that cause unproductive disputes and hinder an autonomous participation of contractors in the market should be deleted. In other words, any barriers to entry should be removed for all contractors to select the competent and appropriate market to enter.

It is possible to improve the efficiency and productivity of work in the construction site by selecting the maintenance contractors through the method of evaluating the objective construction capability of the company. At present, there is a dispute among stakeholders related to the maintenance market in Korea, so a stepwise long-term plan is needed to solve this problem that has been lasting for several decades.

5.2. Plan for resolving excessive competition

In the maintenance market, the contract amount per construction work in the market has been steadily declining. This leads to decrease in not only to the quality of construction work within the Korean maintenance market but also to the competitiveness of the entire Korean construction industry against the global market. Thus, it is necessary to remove any unnecessary terms in law that serve as irrelevant partitions within construction market and allow the autonomy of construction firms to enter the appropriate market. In addition, through evaluation based on construction capability, contractors – both general and specialty contractors – should focus on improving their construction capabilities and developing high-level technology to seek ways to gain competitiveness and advantages in the global construction markets.

6. Conclusion

In this study, it has been concluded via analysis on the current maintenance market structure that the competition among construction firms has become intense along with the quantitative expansion of the market during the past 20 years. Currently, the Korean production system within the construction industry is serving an obstacle to strengthening the competitiveness of the maintenance market, and the market on maintenance and management will keep its stagnation. In order to solve this problem, it is necessary to allow all construction firms to strengthen the capability in not only construction of new buildings but also maintenance of old buildings, and also to allow them autonomy to operate the maintenance market through a phased long-term plan. In the future, the Korean construction industry will continue expanding its maintenance market as it enters the maturity era. Along with this change throughout the time, specialty contractors registered for all types of work need to improve their own competitiveness after any legal barriers are removed.

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Improving efficiency and environmental impact applying JIT logistics and transport consolidation in urban construction projects

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Abstract

The way in which construction logistics is organised has considerable impact on production flow, transportation efficiency, greenhouse gas emissions and congestion, particularly in urban areas such as city centres. In cities such as London and Amsterdam municipalities have issued new legislation and stricter conditions for vehicles to be able to access cities and city centres in particular. Considerate clients, public as well private, have started developing tender policies to encourage contractors to reduce the environmental impact of construction projects. This paper reports on an ongoing research project applying and assessing developments in the field of construction logistics in the Netherlands. The cases include contractors and third party logistics providers applying consolidation centres and dedicated software solutions to increase transportation efficiency. The case show various results of JIT logistics management applied to urban construction projects leading to higher transportation efficiencies, and reduced environmental impact and increased production efficiency on site. The data collections included to-site en on-site observations, measurement and interviews. The research has shown considerable reductions of vehicles to deliver goods and to transport workers to site. In addition the research has shown increased production flow and less waste such as inventory, waiting and unnecessary motion on site.

Keywords: consolidation, construction transportation, just in time logistics, logistics efficiency, urban construction projects.

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1. Introduction

In the Netherlands construction activities are changing from development projects to construction and reconstruction projects in cities. About half of the building activities already take place in cities. These construction activities are causing safety and environmental problems, especially when taking the environmental goals of the local authorities into account. Companies that are operating in the construction chains need to contribute to the reduction of these safety and environmental issues, for instance through CO2 reductions. These companies encounter various problems in the way construction chains operate. Suppliers are faced with unpredictability in the supply because of a lack of detail in planning. Because of the frequent last minute planning, adjusting production and stock levels to the provided demand of goods is difficult. The biggest problem for the carriers is the low utilization rate of the vehicles. This is mostly caused by last minute or dedicated supplies to various construction sites in cities, and notably in city centres. Decoupling the delivery process by means of a construction consolidation Construction Consolidation Centre (CCC) is seen by firms, clients and governments as a potentially liable solution to organize construction chains within cities in a more effective, efficient and sustainable way. Aligning comprehensive logistics management is part of supply chain integration strategies [1].

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1.1. Relevance and potential of construction transport

Last few years particularly cities have restrained the entering of polluting vehicles and improving the inner-city climate and air quality in general. Particularly construction transport is relevant to this aim while typically 30 to 40% of all transport is related to construction. This represents some 40% of vehicle emissions and road congestions. On the other hand studies on load factors indicate a need to act, while these tend to remain structurally under 50%, in few cases down to 15%, and far lagging behind other sectors of transport [2]. In the UK and notably London local government and the industry have shifted to action some years ago with demonstrable results.

The London Construction Consolidation Centre (LCCC) claims that the number of construction vehicles to the sites is reduced 68% [3]. Also LCCC claims that supplier journey time (including loading / unloading time) is reduced two hours [4]. LCCC claims that the delivery performance of goods delivered the first time right is 97% and that there is an availability of goods of 100% within 24 hours [5]. LCCC claims that a reduction of materials waste is generated of up to 15% by reduced damages, less shrinkage and less theft. LCC claims that there is an increase in productivity of the labour force by up to 30 minutes per worker per day [6]. Also improvements of site safety through reduction of materials and packaging on site are reported [7]. To conclude LCCC claims that a reduction of CO2 emissions, as a direct result of the reduction in vehicles, of about 75% [8].

2. Background and method

This paper reports an ongoing research project in the Netherlands aimed at the advancement of innovative logistical solutions and demonstrating the effects in construction practice. The first year of the project four projects have been observed in close collaboration between firms involved, researchers and students. In the projects novel kinds of solutions have been applied and tested, and the effects have been measured via a set of Key Performance Indicators (KPIs). The research project is both aimed at gaining academic insights and advancing logistic in construction solutions such the use of Construction Consolidation Centres (CCC) in the Netherlands, and thus increasing the efficiency of construction as well as reducing the negative effects of construction transport for society.

Based on projects studied in London, discussions and group sessions that were held and earlier research a basic construction supply chain in the Netherlands, using a CCC is set up. Within this supply chain, the Logistics Service Provider is seen as a Cross Chain Control Centre (4C). The description of these solutions applied and the effects envisaged has been based on the GreenSCOR model [9].

2.1. Case selection

To increase our understanding and also uncover areas for further application and research, multiple cases were analysed to explore differences and conformities within and between the four cases (Table 1). We were able to participate in four projects. The projects differ in type, size and location. This has enabled to focus on the differences and conformities how logistics solutions were implemented. The differences give insight how project characteristics affect the dimensions of logistics and the effects of the measures taken.

Table 1: Project cases

	Project A	Project B	Project C	Project D
Type of project	Newly built housing blocks incl commercial spaces and parking basement	Newly built hotel, incl parking basement	Newly built multifunctional expansion of shopping centre, incl. hotel and apartments, and parking basement	Internal refurbishment of office buildings of a larger trade centre incl. the entrance of the centre
Location	Nearby city centre	Urban area close to motorway	In city centre	In city centre
Duration of the project	2014-2016	2013-2015	2013-2019	2014
Size of the building	255 small apartments, 1,500 m2 commercial space, parking basement	18,500 m2 hotel, 4,000 m2 parking for 136 spaces	35,000 m2 shopping, 5 level parking basement for 1,300 spaces	65,000 m2

2.2. Data collection and analysis

The researchers are present as observers in the project team. During construction the Logistics Service Provider coordinates the logistics activities based on the agreements that were set up during the purchasing processes with suppliers and subcontractors. During construction the main constructor sets up a six week planning. This planning is shared with the Logistics Service Provider in the CCC so they can call off goods at the suppliers.

Next to the above mentioned planning a more detailed, weekly planning is set up. This planning gives insight into the day-to-day operation. Also this planning is shared with the Logistics Service Provider. Based on this planning delivery plans are set up for delivery of the goods to the construction site. Also this planning is leading in the call off at the supplier of goods that need to delivered directly to the construction site. These goods then are directly delivered to the construction site. If there are goods that need to be shipped directly to the construction site, these goods will be called off by the CCC.

Based on the KPI framework the personnel of the firms and the researchers involved have measured and reported the deliveries and the transport movement of the project both taking place at the CCC and on site. These measurements and reports have systematically been put in a database and thus produced the input data to calculate the formulas that represent the KPIs.

3. Four factors of influence on construction transport

Construction transport and the effect on process efficiency and the environment can be influenced by different kind of factors. First, transport can be influenced by the way the logistics are managed. More specifically this concerns the extent to which the logistics process can be decoupled and optimised in process parts and load factors of vehicles can be maximised by means of consolidation. Second, the information management of the construction process and the logistics in particular influence the efficiency of construction transport. Third, the packaging and integration of materials into bundles, kits or prefabricated modules that can be shipped and moved in a smart way to the place of installation on site influence the efficiency of transport. Fourth, the extent to which project tendering and purchase contracts consider transport and the effects of it such as CO2 emission as variables or criteria influence the effort contractors, suppliers and logistics service providers put into transport efficiency. At the end of this section these four factors of influence are projected on the four cases, including the logistics measures that were taken in the four projects (Table 2).

3.1. Logistics management; decoupling and consolidation

Decoupling the construction chain can be done by using CCCs. The CCC functions as a decoupling point between supplier and construction site. These centres functions as hubs in a few cases already used in construction as a temporary storage at or near the construction site. The CCC then functions as a decoupling point at which supplies to the CCC are controlled in a ‘push’ way, while goods to the construction site from the CCC are supplied based on the project planning, based on the real and actual need and so controlled in a ‘pull’ way. There is also a possibility that goods are shipped from the CCC, where the CCC is used as a crossdock. By organizing the supply in this way the supplies are more time-independent than deliveries that are directly shipped to the construction site traditionally (Figure 1).

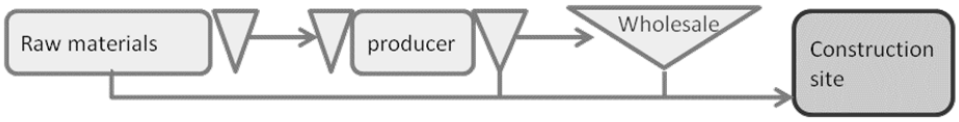

Figure 1: Traditional supply process to a construction site

Materials are not just transported in a JIT manner through the CCC to one site. If required the CCC can be bypassed by supplying goods directly to the construction site, for instance in the case of liquid concrete, full truckloads of heavy material, or supplies that require direct handling on site. Besides multiple sites can be serviced by the same CCC. A CCC can also handle return flows from the construction site including recycling of debris, packaging and equipment (Figure 2).

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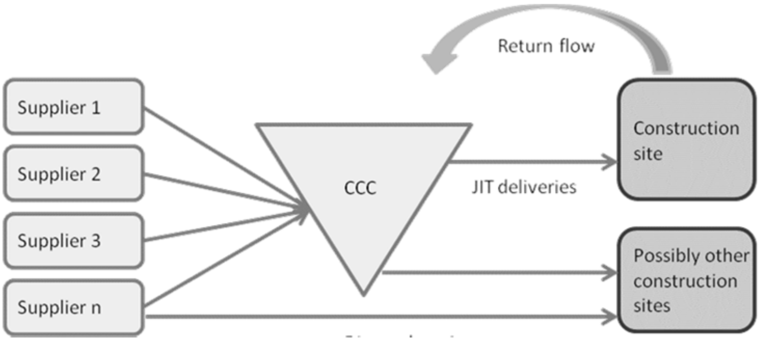

Figure 2: Supply process using a CCC

3.2. Information management; integrated planning and delivery

The planning of the delivery to the construction site is done by the Logistics Service Provider in collaboration with the contractor and subcontractors. Also the suppliers are active in planning the deliveries, particularly the (time-)critical products and the direct deliveries. The overall planning is finalised and controlled by the main contractor at the construction site.

The resources needed at the construction site are called off at the CCC by the responsible person at the construction site through the Warehouse Management Systems (WMS) functioning at the CCC. This request for resources is at minimum one day before the goods are needed at the construction site. The goods can be picked based on this signal and be transported in consolidated shipments to the construction site controlled by the connected Transport Management Systems (TMS).

The balancing of supply chain resources with supply chain requirements is done by the site manager. Orders that are placed come from the project planning. The information in an order generally contains an article code and name, construction part, the planning, location on site. To organize the information about goods to the construction site in a situation with the CCC a so called 'building ticket' can be used. This ticket is a form with which the supplier presents a supply beforehand. Based on the ticket a logistics coordinator can plan deliveries to the construction site.

3.3. Prefabrication; off-site construction and kitting

Particularly at small construction sites there is no space for subcontractors to assemble materials. Therefore it can be a solution that these assembly activities can take place at the CCC. The subcontractor can then assemble goods at the warehouse and have them shipped through regular service to the construction site for installation. This means that goods need to be pulled from stock, taken to the working area where the subcontractor does the assembly work after which the assembled product is put back to stock, meaning new product codes must be generated in the system. Based on the weekly schedule the goods are then shipped to the construction site in a consolidated shipment.

It might happen after assembly modules are becoming hard to handle or kits of material are completely and exactly filled at the supplier's location. In this case a decision can be made that the modules or kits are shipped to the construction site by dedicated deliveries. This means the modules or kits do not pass the CCC and are not put in stock to be called off from there.

This particularly concerns engineered modules, large customized subassemblies, large bulky materials or complete materials packs to finish an entire room in the building for instance. These deliveries are put on site directly and are usually too unpractical to be handled at the CCC. The goods may travel quite a distance from various places. The planning and the time of arrival of those transports needs to be accurate, planned well ahead, to avoid long waiting times once arriving to the site. Vehicle marshalling and control towering are the means to achieve this in particular. If needed the transports are held outside city limits before being called into the city to the site.

3.4. Procurement; MEAT tender and strategic purchasing

Local government have installed restrictions to enter cities and want to keep vehicles out. Also clients who care about sustainability tender via innovative routes and include and reward CO2 reduction as a MEAT criterion (Most Economically Advantageous Tender) in contracts and contractors need to comply to these requirements in their bids in order to win it. This often includes reduction of hindrance for traffic and keeping driving lanes open around and to construction sites. Local governments reward transport and deliveries outside rush hours and even stimulate nightly transport.

In turn some contractors stress the importance and stimulate their suppliers and transport firms to achieve logistics efficiencies. Few studies on supply chain costs rate logistics costs at 10 to 20% of sales prices (https://www.instituteforsupplymanagement.org/). However adversarial procurement by clients tends to lead to adversarial purchasing of subs and suppliers. In turn subs have generally included logistics costs in their prices and contractors have often bargained a good purchase price from suppliers before the discussion about logistics costs would normally start in projects. Therefore contractors shift to strategic and long-term kinds of purchasing and collaboratively with subs and suppliers drive down logistics costs structurally.

Table 2: Logistics measures taken in projects

	Project A	Project B	Project C	Project D
Logistics management	CCC, Buffering, consolidation, waste disposal in same loop, group transport of workers and equipment	Buffer location for trucks close to site	CCC, Buffering, consolidation, waste disposal in same loop	CCC, Buffering, consolidation, waste disposal in same loop, public/ group transport of workers and equipment
Information management	Input from BIM, Solibri into TMS	Online transport tickets per delivery, online WMS and TMS	Online transport tickets per delivery, online WMS and TMS	Printed transport tickets per delivery
Prefabrication, kitting	Prefabricating e.g. of rebar modules at CCC, kitting of daily batches	Kitting of daily batches at CCC, all fit-out material per room per kit	Kitting of daily batches at CCC	Kitting of daily batches at CCC
Procurement, purchasing	n/a	LEED tender with implications for reduced vehicle movements	n/a	CO2 criteria in MEAT tender aimed at reduced vehicle movements

4. Empirical findings and results

In this section we explore the differences within and between the four projects using the KPI framework as a guide (Table 3). The findings are partly qualitative and partly quantitative. The description of the findings partly focus on elements that are not present in the framework or that might deepen our understanding on how to operationalise its dimensions. Within the ongoing research reported the KPI framework is subject of continual development, which is also true for the projects and solutions applied. The fieldwork done at the projects is therefore input for further advancement of the logistics management of the projects (Table 4).

4.1. KPI framework

The KPI framework presented below is based on the GreenSCOR model [9] adapted to a construction context. The indicators and measurements are also based on the construction practices in the UK and the Netherlands applying advanced logistics solutions. The KPIs are formulated to monitor the construction and logistics processes, and also to gain data to measure the effect of logistics measures taken, such as the use of a CCC.

Table 3: KPI framework

	Indicators	Measurement
Reliability	Percentage deliveries on time, and complying to quality and requirements	Amount of deliveries on time and complying to requirements, and reason why not if not, and consequences/costs to fix
Responsiveness	Offloading and waiting times of deliveries on site	Waiting time of trucks before being offloaded on site, and waiting time of personnel and equipment on site before being able to offload
Agility	Lead times of orders delivered from CCC to site, and from suppliers to CCC	Time needed to place and process an order from the CCC and suppliers, and being delivered to the site
Costs	Productivity gains on site, purchase price reductions, transport costs reductions	Less time wasted by workers on site, eliminating logistics cost elements by suppliers, reduction of travel distance and time or bundling of deliveries of suppliers
Assets	transport efficiency, load factor of trucks, consolidation factor of CCC, days of stock at CCC	Transport volume and weight of trucks to and from site; Amount of trucks from supplier to CCC vs CCC to site
Environment	environmental impact, CO2 emission, waste reduction, noise, hindrance, health, safety	Amount of fuel use, amounts of waste, packaging, debris, numbers of complaints, incidents, accidents, traffic jams caused

4.2. Project A

In this specific case the site is located at a canal and thus the potential of water transport had been studied and the consequences for costs, emission and planning. It remained unclear what exactly the extra costs and time use would be of the transfer to water transport. CO_2 would reduce but other emissions such as NO_x and SO_2 would increase because of the fuel used for the boats. Also the materials need to be packed in specific ways to be able to be transported by boat. On site specific equipment had been tried such as floor extensions to be able to easily pull in material and kits from the building elevator onto the floor.

For the information management and support of optimised transport all data needed from suppliers were analysed and validated in the BIM model of the project. This data contained all product specific details, location, time and transport and handling equipment. This data was connected to the planning software on site and the TMS of the transport firm. The data were printed on 'building tickets' that functioned as an order form from site to the CCC and suppliers, which could contain QR codes or tagging via RFID would be possible in later stage.

4.3. Project B

In this case, the building of an new hotel, the logistics management had been concentrating on the tower crane efficiency; the materials supply onto floors and carrying off debris from the floors. The aim was to balance and increase the efficiency of the arrival of deliveries on site, subsequent offloading by the crane, storage on site, the crane taking the materials up to the floor, and installing the materials on the floor. This project did not work with a CCC but was supplied directly from the suppliers plants, particularly concrete, rebar and formwork. This was followed by the HVAC firm whose factory functioned as a place where the materials kits of all materials per hotel room were bundled including all ductwork and finishing.

The site used an online TMS and 'building tickets' including registration of all arriving deliveries from the suppliers and the HVAC firm's location. This led to a continuous information flow to be able to manage the deliveries more accurately, and plan the tower crane's capacity more efficiently. This also reduced the amount of waiting vehicles and traffic jams around the site. As a safeguard, once trucks approached the site they were able to use a buffering location if needed, in case they would arrive untimely.

4.4. Project C

This case is logistically comparable to case B although in this case a CCC was used. Since the project is that large there were dedicated logistics personnel on site as well as at the hub. This personnel was equipped with portable computers with applications to access the online TMS and WMS platform, also including the planning of all cranes, and all entrance and storage locations on site. These integrated systems enabled suppliers and transport firms driving up and down from the site to the CCC to deliver materials and carry off debris in a highly accurate manner. However the size of the project and the amount of suppliers and subcontractors caused quite a bit of improvisation and deliveries that evaded the online system and still caused traffic jams and inefficiencies on the site and around.

Since the project site is located in the very city centre next to the central railway station all disruptions caused quite a bit of congestions. The city is keen to prevent this and reduce emissions caused by vehicles. As an extra measure most of the deliveries were planned outside rush hours and particularly in the early mornings and in the evenings. As a consequence these deliveries took less time and produced less emission.

4.5. Project D

This project had been contracted as a MEAT tender (Most Economically Advantageous Tender) applying CO2 emissions of supplies, travel of personnel and carrying off debris as criteria to the bids of contractors and rewarded this in the appraisal of the bids, besides the price, planning and quality. The winning bid managed to offer the lowest CO2 emission. In the tender a traditional calculation of the emission was given of 42,000 kg the project would produce when executed applying traditional logistics management. The winning bid offered to do the project applying a CCC for all deliveries and carrying off debris, and group and public transport of personnel, resulting in 17,000 kg emission i.e. a reduction of 60%. Based on the registration of all vehicle movements the real emission of the project appeared to be 22,500 kg i.e. a reduction of 46%. This was caused by displacement of the CCC on further distance from the site, and lower load factors than offered in the bid.

Table 4: Empirical findings and results

	Project A	Project B	Project C	Project D
Reliability	Most deliveries arriving on time from CCC to site	More than traditional deliveries arriving on time from suppliers to site	With online transport ticket deliveries within 10 min time frame; without ticket 1:30 hrs	Most deliveries arriving on time from CCC to site
Responsiveness	TMS gives insight in deliveries, taking less time for site personnel to offload	Offloading of all deliveries strictly planned via online tickets and followed up by personnel	Offloading of all deliveries strictly planned via online tickets and followed up by personnel	In most cases site personnel is aware of deliveries planned and take less time for offloading
Agility	Orders from site to CCC come few days to week in advance based on online planning	Online WMS allows orders from site to CCC till two days in advance	Online WMS allows orders from site to CCC till two days in advance	Local WMS at CCC allow orders from site few days in advance
Costs	Prefabrication of rebar and kitting resulted in faster working, less time wasted on site	Bundled deliveries, kitting resulted in faster working, less time wasted on site	Bundled deliveries, kitting resulted in faster working, less time wasted on site	Lower bid caused by lower transport costs and higher productivity based on firms' previous experiences
Assets	Less vehicles to and from site, than traditional, bundling, debris in same loop	Less vehicles to and from site, than traditional, bundling, debris in same loop	Consolidation of deliveries at CCC leading up to 60% less vehicles from CCC to site	Consolidation of deliveries at CCC leading up to 70% less vehicles to site and no return
Environment	Less emission due to less vehicles, less annoyance in neighbourhood of workers not taking parking space	Less emission due to less vehicles, less hindrance around site due to stricter planned deliveries and faster offloading	Deliveries avoiding rush hours took 25% less travel time, 11% less emission as a result	Reduced CO2 emission 22,500 kg during project i.e. 46% less than traditional as based on contract

4. Conclusions

In this paper we observed four project cases applying advanced logistics solutions. The effects of these applications were assessed based on the KPI framework which was constructed for the research project reported. In the six dimensions of the framework all four projects performed better logistically than what the projects would do traditionally. This implied improved transport efficiency and reduced environmental impact of the transport. The observations supported the applicability and usefulness of the framework and the benefits of improved transport and logistics management in construction.

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The KPI framework appeared to be quite useful in describing the level of performance of the projects and the four factors of influence on the construction transport of the projects. Although the scope of the performance and the factors covered a wider range of issues than the framework could assess directly, the framework was able to accommodate also those influences on the projects and the construction transport.

The application of a CCC and other efforts to decouple and consolidate construction transport have been found to play a key role in the logistics solutions and to achieve the effects reported. Second, applications of information management, notably Warehouse Management Systems (WMS) and Transport Management Systems (TMS), are playing an increasingly important role to coordinate the stocks at the CCC and ensure accurate deliveries from the CCC to site. The coordination is starting to extend to the design phase via BIM applications such as Solibri in order to determine daily materials packages to construction sites efficiently. Modularisation and kitting of material packages is a way forward in which much is to be gained in terms of production. Fourth, tendering and purchasing based on MEAT criteria rewarding CO2 reductions by clients and governments, and also construction firms towards suppliers and transport firms will likely encourage further efforts to improve transport efficiencies and reduce the environmental impact of construction transport.

Notwithstanding the benefits and potential, the scope of these improvements focus mainly on the 'last mile', notably the transport from the CCC to the site. In most cases though the deliveries from suppliers to the CCC are not acted upon, although there is an improvement potential here too. Further, and this goes for the application of the KPI framework as for ICT instruments mentioned, firms and individuals along the supply chain must be aware and systematically use and keep up those tools to be effective and cause the desired impact.

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Investigating the Productivity Based System of Labour Intensive Works in Delivering Road Infrastructure in Rural Communities in Ghana

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Abstract

The Labor-intensive Public Works (LIPW) has rehabilitated 792km Feeder Roads, 192 Small Earth Dams & Dugouts (that is ensuring the harvesting of 21,195,764 cubic meters of water for the rural poor) and 2,550 hectares of degraded public/community land through tree planting and other biodiversity restoration activities. However systematic operations risk-rating on Technical Design of Project was rated low. The aim of this paper is to investigate the Productivity based system of Labour Intensive Works in delivering road infrastructure in rural communities in Ghana**.** The objectives are to identify the drivers affecting performance of management- and control-related activities that occur in during labour intensive works and to determine the characteristics of workers that affect the performance of labour intensive works. Purposive sampling technique was adopted to select 12 districts were the labour intensive projects on road construction were carried out. Random sampling technique was adopted to select 24 contractors from the study population which has total contractors of 180. Furthermore stratified sampling method was adopted to select 120 participants of which 24 of them are facilitators, 24 time keepers, 24 site engineers, 24 contractors, 12 district engineers, 12 GSOP Desk officers. The study adopted the exploratory factor analysis. The exploratory factor analysis was used in this research study to confirm the reliability and validity of labour productivity. Attitude of site personnel was ranked as the leading factor influencing the management related activities with a mean score of 3.81 while Knowledge of project technology and Accuracy of technical information followed having a mean score of 3.60 and 3.50 respectively.

Keywords: Ghana; labour intensive works; productivity; road; task.

1.0. Introduction

The Labour Intensive Public Works (LIPW) is one of the strategies that various governments have employed to curtail the aforementioned problem. Bentall [1] defined labour-intensive approach as an approach where labour is the dominant resource for carrying out works, and where the share of the total project cost spent on labour is high (typically 25% - 60%). It is observed that the LIPW can aid the provision of needed material and financial resources to promote rural development programs that are geared toward reducing rural-urban migration as being championed in Ghana by the District Assembly concept introduced in the 1980's. The Government of Ghana through the

Ghana Social Opportunities Project (GSOP) has instituted a number of social protection interventions as a safety net for the poor and vulnerable in the society.
The Labour Intensive Public Works (LIPW) projects have two main objectives; one is the quick generation of employment to the poor unskilled labour. The second objective is ensuring that government performs its mandate of providing and maintaining infrastructure in order to promote the development of the country. Recently, due to global economic crisis, LIPW projects have assume larger importance as major safety nets providing income for the poor people and ensuring that they have adequate food that can sustain them. [2] proposed three models for LIPW projects. The first model sees LIPW as a safety net intended to provide cash income to self-selected participants in times of need e.g. seasonal income shortages or to respond to nation-wide or region-wide shocks such as a drought [3]. The second model also sees LIPW project as a longer term safety net intended to provide a cushion, mainly as a poverty alleviation project but not totally eliminating poverty.

[4] define labour productivity as the rate at which tasks are produced, especially the output per unit of labour. Concise dictionary defines it as "work performed per unit of time" or "time to perform unit of work." The goal in managing construction tasks is to produce the optimum output per labor hour. The output desired naturally complies with project requirements for materials, construction techniques, appearance, performance, and workmanship. Productivity rates should be established in the estimate regarding perception of conditions and project requirements. The productivity rates used in the estimate are generated from historical data, both from the contractor's own records and from a variety of available references.

1.1 Problem Statement

In recent years the rate of delays in the construction 'industry seems to have raised a general concern by the general public as they are striving to find out what actually is happening considering the basic resources available to construction firms. Due to the increasing level of constructing a building, the general public continues to complain that the average cost of designing and building a house is of high cost. Most Building construction companies are trying to find ways which might improve labour output constants in the industry. Labour being one of the greatest risks encountered in the construction sector, it should be controlled and continued improvement of sites is necessary to determine its performance.

[5] argues that investment in infrastructure has a huge potential to redress the high unemployment and poverty levels in South Africa and also to correct the skills deficits in disadvantaged communities. Experience elsewhere in Africa, there are reasons for considering that properly formulated labour-intensive public works programmes and projects could be established to construct and maintain the required physical infrastructure, thus creating employment, skills and institutional capacities [5].

The methods used in measuring productivity in the construction company cannot be the same for other workplaces. This is due to the very nature of labour productivity as a qualitative category [6].

[7] asserted that inefficiency in the construction industry is attributed to labour factors which appear to lead many projects overrun across the globe. Labour being more unpredictable than other project-cost components, it is necessary to understand the effects of different factors on labour productivity. Previous researchers had claimed that an increase in productivity can reduce the labour cost in a direct proportion and an increase in idle time of workers waiting on material. The construction industry is labour-intensive and relies heavily on the skills of its workforce while the workforce is the industry's most valuable asset, which at the very least, accounts for over a

quarter of the total project cost. Labour can significantly influence the cost, schedule, and quality of a construction project [8].

[9] asserted that the construction industry's performance in terms of cost, time, quality, safety and health of its workers, the durability of its products and the satisfaction of its stakeholders, are inadequate due to the low productivity.

The impact that may occur is the need for new or additional material, constraints and equipment, which affect the sequence, duration and schedule of work packages. Low productivity is common in the construction industry in developing countries like Ghana and this could be attributed to poor labour productivity due to the labour-intensive nature of construction activities in these countries ([10] and [11]). Often, labor productivity is a key factor contributing to the inability of many contracting organisations to achieve their project goals, which include, most importantly, the profit margin.

1.2 Aim of the study

The aim of this paper is to investigate the Productivity based system of Labour Intensive Works in delivering road infrastructure in rural communities in Ghana**.**

1.3 Objectives

The objectives are to identify the drivers affecting performance of management- and control-related activities that occur in during labour intensive works and to determine the characteristics of workers that affect the performance of labour intensive works.

1.4 Scope of the study

The study focused on the drivers affecting productivity of labour intensive public works on feeder roads construction in Ghana hence the study concentrated mainly in five regions where labour intensive public works are carried out in the Accra zone(Eastern region, Greater Accra, Central Region, Volta region, and Western Region) 24 road construction sites were considered.

2.0 **Drivers Affecting Labour Productivity Performance of Projects**

[12] suggest that many different factors can affect labour productivity on a project. Project supervisors should be familiar with the most common factors affecting labour productivity, which include the following:

i. Lack of supervision or poor supervision
ii. Lack of coordination of subcontractors with work activities
iii. Improper or insufficient material available for tasks
iv. Poor jobsite layout
v. Lack of proper tools for work activities
vi. Congested work areas
vii. Poor housekeeping
viii. Accidents and unsafe conditions on the jobsite
ix. Adverse weather conditions
x. Poor lighting in the work area
xi. Inadequate heat or ventilation in the work area

xii. Tardiness of excessive absenteeism
xiii. Uncontrolled starting time, quitting time, and lunch and breaks
xiv. Shortage and location of close parking, changing rooms, restrooms, and drinking water
xv. High employee turnover
xvi. Use of improperly or poorly trained craftspeople
xvii. Supervisors not making timely decisions
xviii. Poor attitude among employees
xix. Construction mistakes caused by complexity, poor drawings, or lack of communication
xx. Impact of changes on production work

2.1.Poor Weather

Bad weather often is not adequately anticipated, forcing changes in schedules, production, and damage to completed work. Productivity decreases in poor weather to varying degrees, depending upon the severity of the weather and the work tasks. Weather can affect some construction materials, such as concrete and mortal; as well as the efficiency of the labour. When protective clothing, such as rain gear or cold-weather gear, is necessary, labour is impeded. [13]

Initial project planning should consider seasonal weather conditions. Anticipating bad weather and Rainy weather requires protection of the work area, maintenance of haul roads and jobsite access, and dry shack provisions for changing clothes and eating lunch. In fine-grained soils, rain will produce mud, which slows work considerably. Preparation for these conditions can be made, with provisions such as preparing haul roads and jobsite access with a gravel surface and adequate drainage. Planning weather-sensitive activities around it can reduce some of the impact.

2.2 Material Problems

Late deliveries require crews to move to other work areas, halting the production at one area and requiring startup of new work activities. Also, shortages can stop crews from working, forcing workers to be laid off for short periods of time. If crews are required to carry materials long distances before work can occur, productivity is affected. Double handling of materials will result in damage to materials, increased waste, and lost time.

2.3 High Labor Turnover

High labour turnover may be an indication of poor planning, general unrest, and lack of leadership by the foreman and/or superintendent. New training may be required each time this situation occurs, and high levels of unrest or low morale can lead to a slowdown of work.
Jobsite management must employ the correct labor for the project. It is important that jobsite management be experienced in the type of construction on the project.

Despite the fact that foremen are technically considered labour rather than management, they are an important bridge between management and labour, leading the crew in techniques, methods, and productivity. Trained foremen in labor techniques, safety procedures, crew management, productivity control, and cost control are essential for effective labor management.

2.4 Accidents and Unsafe Conditions

All work will quickly come to a halt when an accident occurs on a jobsite. Employees who do not feel safe tend to be overly cautious when performing their work tasks, thus noticeably slowing

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production. A clean and safe jobsite is conducive to obtaining maximum productivity from labor crews.
Many construction companies realize the importance of safety on jobsite production. Contractors are required by state and federal regulations to have in place an active construction safety program, but the degree of implementation on the jobsite is a matter of commitment by the construction company. The impact of a safe and clean jobsite on productivity cannot be understated. The cost of keeping a clean jobsite is considerably less than the cost of lost productivity, accidents, and safety fines associated with poor housekeeping.

2.5 Working Overtime
Working longer days or adding additional days of work on a prolonged basis will result in increased injuries and safety problems. As workers become tired from longer periods of work, they begin to adjust their pace or slow their productivity to avoid fatigue. When forced to work overtime, an employee may become disgruntled, causing low morale among other employees. In the same respect, if overtime is offered to one employee and not another, jealousy may become a problem among employees [14].

3.0 Research Methodology

3.1 Population
The study population is 60 district assemblies in Ghana where the labour intensive public works is carried out in Ghana and all contractors who are registered with the Ghana Social Opportunity Project. They are 200 of them and maintain a total workforce of 12,000 participants.

3.2 Sample size and Sampling Techniques
Purposive sampling technique was adopted to select 12 districts in Accra zone that comprises districts in five regions out of the ten regions in Ghana namely Eastern Region, Greater Accra Region, Central Region, Volta region and Western region out of the 60 districts where the labour intensive projects on road construction were carried out. Simple random sampling technique was adopted to select 24 contractors from the study population which has total contractors of 36 in the Accra zone. Furthermore, stratified sampling method was adopted to select 120 participants of which 24 of them are facilitators, 24 time keepers, 24site engineers, 24 contractors, 12 district engineers, 12 GSOP Desk officers.

3.3 Data Analysis
Exploratory factor analysis would be adopted. Factor analysis would be used to classify the factors into components. At this stage, components classified on the basis of the relevant literature review (the equipment, workers, work characteristics, materials, and management and control components). The components that would be properly classified need to be examined. Regression analysis would be the last stage of the statistical analysis in which the components that significantly influenced labour productivity satisfaction in labour intensive works would be identified. The significance of the components would be analysed, and insignificant components need to be discarded at this stage.

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4.0. Findings and Discussion

Table.1: Performance of management- and control-related activities in Labour intensive works

Item	Activities relating to management and control	Level of performance for in your company Least Influential ← → Most Influential							
		1	2	3	4	5	Total	Mean	Ranking
1	Delegation of responsibilities	19(19)	19 (38)	23 (69)	27 (108)	32 (160)	394	3.28	7th
2	Integration of project information	30 (30)	27(54)	19 (57)	42 (168)	2 (10)	319	2.65	11th
3	Use of incomplete drawings	29 (29)	24 (48)	31 (93)	22(88)	14(70)	328	2.73	9th
4	Use of complex designs in the provided drawings	35(35)	17(34)	31 (93)	21 (84)	16 (80)	326	2.71	10th
5	Presence of variations in the drawings	30 (30)	15 (30)	37 (11)	21(84)	17(85)	240	2.00	12th
6	Project planning	19(19)	18(36)	23 (69)	26 (104)	34 (170)	398	3.32	6th
7	Scheduling of project activity	18 (18)	19(38)	20(60)	38(152)	25 (125)	393	3.28	7th
8	Supervision of subordinates	18 (18)	17 (34)	18(54)	37 (148)	30 (150)	404	3.37	5th
9	Communication between head office and site	15(15)	15(30)	25(75)	35(140)	30 (150)	410	3.42	4th
10	Involvement of site managers in contracting meetings	20(20)	19(38)	25(75)	30(120)	26(130)	383	3.19	8th
11	Attitude of site personnel	7(7)	8(16)	20(60)	50(200)	35(175)	458	3.81	1st
12	Knowledge of project technology	8(8)	16(32)	24(72)	40(160)	32(160)	432	3.60	2nd
13	Accuracy of technical information	10(10)	19(38)	26(78)	30(120)	35(175)	421	3.50	3rd

Among the thirteen drivers affecting the performance of management- and control-related activities in labour intensive works attitude of site personnel was ranked as the leading factor influencing the management related activities with a mean score of 3.81 while Knowledge of project technology and Accuracy of technical information followed having a mean score of 3.60 and 3.50 respectively. Presence of variations in the drawings was the least ranked with mean score of 2.0 this is because most of the drawings for the construction are always complete hence no difficulty in such situation.

Table 2 Performance of Characteristics of workers in Labour intensive works

Item	Characteristics of workers	Level of performance for in your company Least Influential ← → Most Influential					Total	Mean	Ranking
		1	2	3	4	5			
1	Workers' having formal training in labour intensive works	18(18)	18 (36)	20(60)	29 (116)	35 (175)	405	3.38	11th
2	Employees' level of experience to do their work	12 (12)	20(40)	26 (78)	40(160)	25 (125)	415	3.46	9th
3	The number of multi skilled project personnel in the company	14 (14)	19 (38)	20 (60)	47(188)	20(100)	400	3.33	12th
4	Employees' knowledge of scientific techniques	16(16)	17(34)	35(105)	23(92)	29 (145)	392	3.27	14th
5	Promotion opportunities for employees	18 (18)	18 (36)	28 (84)	34(136)	22(110)	384	3.20	15th
6	Employees level of awareness of company policy	16(16)	22(44)	35 (105)	22 (88)	25 (125)	378	3.15	17th
7	The company's incentive scheme for good performance	7(7)	18(36)	15(45)	45(180)	35 (175)	443	3.69	8th
8	Opportunities for employees to exercise their skills	25 (25)	20 (80)	28(84)	28 (112)	19 (95)	396	3.30	13th
9	Management response to settle employee's grievances	4(4)	15(30)	21(63)	30(120)	50(250)	467	3.89	3rd
10	Workers' knowledge of career prospects	13(13)	20(40)	40(120)	28(112)	19(95)	380	3.17	16th
11	Workers' attitude towards the job they have to execute	6(6)	10(20)	12(36)	52(208)	40(200)	470	3.92	2nd
12	Likelihood workers are paid on time	0(0)	0(0)	15(45)	60(240)	45(225)	510	4.25	1st
13	Quality of transportation facilities for workers	25(25)	45(90)	0(0)	28(112)	22(110)	337	2.80	20th
14	Level of safety achieved on projects	10(10)	10(20)	25(75)	35(140)	40(200)	445	3.71	7th
15	Degree to which safety standards on a project comply with legislated criteria	2(2)	19(38)	45(135)	35(140)	19(95)	410	3.42	10th
16	The usage of safety wear on site	0(0)	2(4)	48(144)	50(200)	20(100)	448	3.73	6th
17	Likelihood older workers will be replaced by younger workers	15(15)	32(64)	19(57)	40(160)	14(70)	366	3.05	19th
18	Employment of young workers on projects	7(7)	10(20)	15(45)	48(192)	40(200)	464	3.87	4th
19	Employment of older workers from villages	22(22)	19(38)	30(90)	20(80)	29(145)	375	3.12	18th
20	Incentives used to attract young people into sector	0(0)	0(0)	18(54)	47(188)	55(220)	462	3.85	5th

As seen in table 2 Likelihood workers are paid on time had a mean score 4.25indicating as the most influential drivers of Characteristics of workers that affects the productivity of labour intensive works. Workers' attitude towards the job they have to execute ,management response to settle employee's grievances and incentives used to attract young people into sector had mean score 3.92, 3.89, and 3.85 respectively also had impact on the performance of the labour intensive works. Quality of transportation facilities for workers had the least mean score of 2.80 since most of the labourers were living in the communities where the projects were carried out hence did not have any bearing on their productivity at site.

5.0 Conclusion

Many people who claim to be discussing productivity are actually looking at the more general issue of performance. While productivity is a fairly specific concept related to the ratio between output and input, performance is a term which includes almost any objective of competition and manufacturing excellence such as cost, flexibility, speed, dependability and quality.

A successful construction project is one that is completed on time, within budget, meets specified standards of quality, and strictly conforms to safety policies and precautions. All of these are feasible only if the premeditated levels of productivity can be achieved. All the same, productivity or lack thereof, is one of the construction industry's most prevalent problems. Due to the nature of construction projects, its importance to society and the existing economic resources, more emphasis should be given to improving productivity.

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Involving Knowledge of Construction and Facilities Management in Design through the BIM Approach

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Abstract

The construction industry has increasingly realised the importance of knowledge. Accordingly, various strategies and tools have been applied over the years to support knowledge management (KM). In particular, building information modelling (BIM) is a technology that has recently emerged in the construction industry. BIM is an object-oriented and parametric-based tool with the features of digital visualisation, life cycle simulation, coordination and collaborative environment. Consequently, many studies have been conducted to explore these four aspects. However, existing studies on BIM-based management mainly focus on the information level. By contrast, only a few studies have explored KM under the BIM environment. Therefore, this study explores the potential and expectations of BIM-based KM for the early application of knowledge of construction and facilities management (FM) into the design stage. A total of 30 semi-structured interviews are conducted to collect qualitative information from the AEC industry. The existing KM practice is explored based on the analysis of the collected qualitative information. Thereafter, a discussion is presented on how the BIM-based KM can be used to mitigate the current KM challenges. Lastly, this study presents the expectations on BIM-based KM for involving the knowledge of construction and FM into the design phase. Overall, this study provides new insights into the transformation of research focus from BIM-based information management to BIM-based KM.

Keywords: Building information modelling (BIM); knowledge management; construction project management; collaboration

1. Introduction

Many industries have realised the importance of knowledge and the architecture, engineering and construction (AEC) industry is no exception. Knowledge is applied within this industry to address a variety of difficulties and improve project performance, such as control of time [1] and cost and avoidance of health and safety accidents [2]. Consequently, knowledge management (KM) has become an important task for construction-related organisations and has received extensive attention in the academic circle. However, KM in construction projects is challenging because of the its temporary nature and the variety of disciplines involved in it [3, 4].

To enable KM to meet the additional requirements caused by the increasing complexity of a project, information technology (IT) tools and IT-based techniques are developed for knowledge capture and retention, knowledge sharing and knowledge reuse. Meanwhile, IT-supported KM is also used in each of the project stages, such as design [5], construction [6] and operation and maintenance (O&M) [7]. In addition, the focus of research began to shift to KM throughout the projects' life cycle because of the emphasis placed recently on the improvement of the project life cycle performance [8].

Building information modelling (BIM) is an emerging technology and is extensively used in the AEC industry. The National Institute of Building Sciences (NIBS) [9] explained that BIM is a digital representation of the physical and functional characteristics of facilities. The geometric and non-geometric information included in BIM models can digitally describe a building and its elements. Existing studies on BIM can be classified into two main aspects, namely

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technical- (e.g. clash detections, energy simulations, time and cost evaluations, data compatibility) and BIM process-related (e.g. collaboration, information sharing, BIM adoption and BIM-based procurements).

However, existing studies have only focused on the information rather than the knowledge level within projects. Accordingly, only a few studies have applied BIM to facilitate KM, although such research does not consider the BIM-based KM under a collaborative environment. In addition, no studies have yet to systematically explore BIM's potential for KM and the expectations and needs of BIM-based KM for collaboration. Therefore, the current study aims to fill in this knowledge gap by exploring methods to involve knowledge of contraction and FM into the design stage under a BIM environment.

This study firstly explores the existing early involvement of contractor and FM teams and identifies BIM's potential for KM thereafter. Lastly, the expectations of BIM-based KM for early contractor involvement (ECI) and early FM involvement (EFMI) are investigated.

2. Theoretical framework and literature review

2.1. Existing IT-supported KM in construction

Many KM related techniques have been used in construction projects. In addition, some ITs are also used to support KM techniques. The most common KM techniques used in current projects include brainstorming, communities of practice, face-to-face interactions, training and post-project review. Since construction projects are becoming increasingly complex, the involvement of various disciplines in projects is required. As a result, relying solely on people to manage knowledge is challenging. Existing studies show that IT has been applied to every process of KM in construction projects.

IT-based knowledge capture has developed from audio diaries [10] to Web 2.0 applications [6, 11]. For example, Soibelman et al. [5] developed a web-based design review checking system to obtain personal knowledge from projects and transfer such knowledge into the organisational level. Woo et al. [12] explained that knowledge of construction projects is mainly tacit and difficult to capture. Therefore, a few IT-based KM methods are developed to aid the capture of tacit knowledge, such as the ontologies used by Ugwu et al. [13] and network-based knowledge map used by Lin et al. [14]. Although the existing studies have begun to focus on the capture of tacit knowledge, only a few previous studies have explored the retention and storage of tacit knowledge. Consequently, the reusability of tacit knowledge is also inefficient. In addition, the use of post-project reviews as the main knowledge capture technique indicate that staff turnover and reassignment often suffer from missing knowledge during project implementation because of time lapse. To mitigate this issue, a web system was developed to achieve the proposed concept of "live" capture and reuse of knowledge [11].

Numerous studies have explored the use of ITs to support knowledge sharing. An intranet is often used to share knowledge within an organisation. The emergence of the World Wide Web enables such sharing of knowledge across organisations. However, the web integrated to KM can only support explicit knowledge sharing, whereas the contribution of tacit knowledge sharing is limited [15]. To promote tacit knowledge sharing, a few studies combine ITs with KM techniques, such as community of practice, which can enhance the interaction for this type of knowledge sharing [16].

Knowledge reuse comprises two aspects, namely, knowledge retrieval and knowledge adaptation. Many studies explored how ITs can facilitate knowledge retrieval and the retrieval scheme includes keywords [14], ontologies [17] and data/text mining [18, 19]. However, these studies fail to consider knowledge retrieval under collaboration. Existing studies lack IT-based knowledge adaptation.

Databases are extensively used in knowledge storage, requires a predefined classification structure, and is labour consuming and subjective. To mitigate this challenge, an automatic knowledge classifier is developed to be combined with the database developed by Chi et al. [20].

2.2. BIM-based KM

Presently, three methods are used to capture knowledge under the BIM environment. The first method is to capture and retain knowledge by using predefined customised parameters in the BIM model [21]. The second approach is using application programming interface to manipulate the data retained in the BIM model through external applications [22]. The last method combines BIM with a specialised knowledge capture tool [23, 24]. BIM enables users to create customised parameters to add the knowledge related to the building objects and project [25]. Deshpande et al. [21]

developed a KM system, in which different user-defined parameters, such as lessons learned and involved subject experts, are used to capture knowledge. Although existing studies utilise predefined parameters for knowledge capture, no studies explore how the structure of the parameters suits the collaboration among the different disciplines. Only a few studies focus on knowledge capture and reuse. In addition, research on BIM-based KM fails to consider the capture and reuse of tacit knowledge.

Knowledge sharing under the BIM environment is mainly based on the combination of BIM and knowledge-sharing tools, such as web application [26] and software [27]. BIM combined with web-based applications can use the accessibility, search capability and social interaction of web-based technologies and maximise the 3D description and parametric modelling features of BIM. Ho et al. [26] established a BIM-based web application to share knowledge in a text format. However, knowledge in text format is difficult to understand, thereby impeding collaboration. BIM as a 3D presentation tool can be used for visualised explanation of text-based knowledge.

Existing studies have yet to intensively explore knowledge retrieval under the BIM environment. Park et al. [28] and Ding et al. [29] applied ontology-based knowledge representation to aid knowledge retrieval under the BIM environment. To implicitly or imprecisely retrieve knowledge, Gómez-Romero et al. [30] combined fuzzy description logics with ontology in the BIM-based system to improve the knowledge retrieval results, in which the retrieval mechanism is not either “true or false” but relatively holds the truth. Additionally, case-based reasoning is introduced in the BIM environment for knowledge storage and retrieval [25].

2.3. Early involvement of knowledge of construction and FM into the design stage

ECI is proposed by the UK Highways Agency and aims to engage contractors earlier than normal to provide assistance with design [31]. ECI is a relationship between contractor and client or design team, thereby providing an opportunity for contractors to apply their knowledge into the design. During the design stage, contractors can provide suggestions to support the estimation of schedule and budget and the selection of materials and construction strategies.

Previous studies have stressed the benefits of ECI, such as improved constructability [1, 32–34], enhanced relationship [32, 35, 36], facilitation of innovation [32, 34, 37, 38], informed decision-making [1, 31, 34] and avoidance of potential risks and accidents [1, 31–34, 38–40]. Additionally, a few other aspects of a project, such as waste reduction, quality improvement, environment impact control, sustainability and defining the practical objectives, can be assisted through ECI [40]. ECI can also facilitate in easily meeting the requirements of clients [31].

The purpose of EFMI is to consider the potential problems that may occur in the operation stage during the design stage because FM teams are knowledgeable in the O&M of buildings and end users’ special needs for business objectives [41]. Therefore, EFMI has obtained intensive attentions from the industries and academia.

A few existing studies discussed the benefits of EFMI. Firstly, EFMI assists the design team to identify potential design errors and ensure the operability, maintainability and serviceability of buildings, including material selection and space layout for equipment installation and accommodation [42, 43]. Mohammed and Hassanain [43] further indicated that feedback from the design team during the EFMI process can also improve O&M in the future. This scenario can be considered as a knowledge loop. Additionally, the FM team can recommend appropriate and efficient equipment and systems based on durability and reliability because this team has the experience in maintaining building systems [43, 44]. Clients/end users can also obtain benefits from EFMI, such as achievement of their expectations [43, 44], guarantee of particular systems or objects’ performance [45], adaptability for their business needs [41], reduction of life cycle cost [43, 44] and flexibility and adaptability for future changing needs [41, 43].

Apart from the advantages of ECI and EFMI, barriers and challenges are also identified by existing studies (see summary in Table 1).

Table 1. Barriers to ECI and EFMI

Barriers to ECI	References	Barriers to EFMI	References
Responsibility allocation	[31, 46]	Lack of the understanding of benefits	[42, 45]
Reluctance to change	[1, 33, 46]	Lack of common knowledge	[42, 47, 48]
Lack of the understanding of benefits	[1, 40]	Lack of technical supports	[48, 49]
Lack of mutual trust and respect	[46]		
Loss of competitiveness	[32]		
Lack of technical supports	[34, 46, 50]		

3. Methodology

To collect in-depth information from the industry, the current study opted for semi-structured interviews as the research method. A total of 30 experts from the construction industry were interviewed. All interview participants have extensive knowledge and experience in BIM and are working in different organisation types, including design, construction, FM, consulting company and client. The reason for the range of organisations is that the current study aims to explore the collaborative KM in the design stage. Thus, the interviewees' project functions included architect, consultant, contractor, facilities manager, structural engineer and client. Additionally, they were selected from 30 different companies with different sizes, tasks and locations in the UK and Ireland.

The pre-designed interview paradigm was developed and revised based on the literature review and four pilot interviews, respectively. The interview structure was divided into three main sections. The first section aimed to identify the interviewees' personal information and their organisation information. The second section explored the current KM practice in construction projects, which includes the existing KM tools and techniques, KM processes (i.e. knowledge capture and retention, knowledge sharing, knowledge reuse) and BIM's potential for KM. In the third section, interviewees were asked to explain how the contractor and FM team were involved in the design stage of the project. Thereafter, they provided their perspective on how BIM can aid this early engagement process. Furthermore, the interviewees were asked to specify their needs for and expectations of a BIM-based KM system.

Each interview was recorded using a voice recorder with permission from the interviewees. Furthermore, the interview audio will be transcribed into a Word document format for analysis.

4. Findings and discussion

4.1. ECI and EFMI in the current construction industry

The interview results indicate that the interviewees agree that the most efficient ECI should occur before the start of the design drawing rather than during the design process. Interviewees from the design disciplines explained that a client occasionally asks the design team to present their ongoing works and the contractor will be asked to conduct value engineering for the client. Consequently, a few design schemes should be changed, thereby increasing the design team's workloads. Hence, the design team is reluctant to show their design to the contractor to avoid the additional work caused by redesigning. Moreover, a few interviewees suggested that subcontractors should be considered during the ECI process because they have substantial knowledge of technical details and their knowledge is considerably targeted to such specific aspects. One of the interviewees also reiterated that several subcontractors had their own design teams. Hence, they will conduct the design work based on the project design team's general requirements and description. If they need to further discuss with the project design team, then they can ask the main contractor to hold a meeting for them. Furthermore, a few interviewees mentioned that the contractor is invited to participate in the design coordination meeting, which can also be considered as a form of ECI.

A few interviewees believed that when FM participated in the design meeting, the design drawings or models should be presented to facilitate an improved understanding of the design intentions. This situation may be caused by the lack of design knowledge and geometric thinking of the FM team compared with the contractor. The information collected from the interviews was used as basis to conclude that a few decision points in certain projects are set during the design stage. The FM team will be brought to these decision point meetings to comment on how the design should proceed. By contrast, a few interviewees believed that EFMI should not overly rely on the design drawings, because the FM team can lack the design knowledge and skills in geometry. Hence, they need additional time to understand the design drawing. Therefore, if the FM team overly relies on the design drawing, EFMI will become inefficient. These interviewees suggest involving FM in a creative manner, particularly when the drawing work has not started. Moreover, the FM team can be involved in the design as paid consultants to provide suggestions, although they may not be appointed as the final FM team of the project. Two interviewees from the design discipline mentioned that they occasionally use the data from the FM team to support their design, such as maintenance and replacement period cycles of materials or components. If the early involvement of the FM team is not approved by the end user, this team may fail to reflect the end user's needs during the design stage, such as the spatial layout requirements.

4.2. BIM's potentials for KM

The interview results indicate that the three potentials of BIM related to KM are knowledge capture and retention, proactive KM and visualisation-supported KM.

Within the BIM model, description data can be added to the related building objects, such as materials, size and colour. The BIM applications also enable users to create customised parameters, which can be used to capture and retain knowledge. For example, customised parameters can be used to record the knowledge in the BIM model to instruct the contractor how to install or construct a specific part of a building. Such customised parameters can also retain knowledge to guide the FM team on how to operate/maintain the facilities during the O&M stage. Interviewees even suggested that the client/end user should be encouraged to request the knowledge that they need. Accordingly, the design team and contractor will input the required knowledge in the BIM model during the design and construction process. This knowledge-rich model will be forwarded to the FM team for O&M.

Interviewees also believe that the visualisation of BIM can aid KM, particularly for the collaborative KM. A possible motivation for this is that a few collaborators, such as the FM team and client/end user, may lack geometric thinking and design knowledge. If 3D visualisation provides support, then the FM experts and client/end user can easily understand the design intention. They can also intuitively see if the design meets the O&M requirements, building functions and business objectives. Thus, they can provide their suggestions to improve the design. For example, doctors and nurses can use 3D visualisation as basis to suggest to the design team what the layout of the operation room should be and the space needed to transport equipment.

The interviewees explained that BIM has the potential to facilitate proactive KM. They proposed this idea mainly based on the detection, simulation and analysis features of BIM. BIM enables a proactive clash detection. Consequently, design teams can proactively solve these potential problems using their experience and knowledge. BIM can also provide the simulation results for the design, such as energy consumption and sun path movement, thereby assisting project teams to optimise their design. This simulation feature prompts life cycle issues to be considered in the design stage. Additionally, interviewees mentioned that BIM can provide early analysis, such as construction cost, construction program and lead time of suppliers, thereby providing early scenarios to project teams. Accordingly, they can make an informed decision based on their knowledge and experience.

4.3. Expectations of BIM-based KM for ECI and EFMI

The interview results indicate that the interviewees proposed the expectations of the KM processes, namely, knowledge sharing, knowledge capture and retention and knowledge reuse, as well as provided a few other expectations of the proposed BIM-based KM for ECI and EFMI.

Section 4.2 reiterates that the interviewees did not point out that BIM has the potential to share knowledge directly. However, they believe that combining BIM with knowledge-sharing platform can substantially facilitate the efficiency and effectiveness of knowledge sharing. Therefore, the interviewees suggested that the BIM-based knowledge-sharing platform should enable people to comment on the related building objects of BIM. Additionally, they also believe that a discussion module should be included in BIM-based KM, thereby facilitating the interaction during knowledge sharing. The interviewees even think that embedding a common data environment (CDE) to BIM-based KM is necessary. The likely reason for this opinion is that CDE as a central repository includes project-related documentation and graphical and non-graphical data. Although CDE is currently applied exclusively to the information level, such an environment can also be theoretically applied to the knowledge level. Consequently, project parties can share and acquire knowledge on a central platform and avoid errors and conflicts caused by the inconsistency and dispersion of knowledge. Moreover, storing knowledge in the central repository provided by CDE can alleviate the problem of knowledge redundancy in the BIM-based KM system. The expectations of knowledge-sharing mentioned in the interviews are all about explicit knowledge. Although the interviewees understand the importance of tacit knowledge, they did not propose any relevant strategies to manage tacit knowledge in this system.

The interviewees also expect that the BIM-based KM can be used to capture and retain knowledge. The possible reason is that the customised parameters of BIM enable users to add a descriptive natural language. Thus, the customised parameters of BIM enable people to add knowledge related to building objects or even projects. Although BIM can be regarded as a single central repository to capture and retain knowledge, interviewees believe that reliability of importing knowledge from the BIM model into the external database for improved management. The interviewees also reiterated that during the process of knowledge retention, A common "language" should be used for the knowledge index because this BIM-based KM system is for the collaboration of different disciplines in the design stage. The interviewees also explained that with the increasing knowledge in the proposed system, the problem of redundancy should be avoided. The interviewees suggested two solutions. One solution is to generalise knowledge, while the other is to update the previous knowledge based on the latest problems. One interviewee explained that he expected that this system can enable knowledge transfer from project to organisational level.

The interviewees listed three expected methods of knowledge presentation. The first method is to present knowledge in case studies, in which the background information of previous knowledge can be considered when people reuse the knowledge for a current problem. The second method is to link knowledge with related building objects in the BIM model, by which the visualisation of BIM can be used to obtain an improved understanding of the knowledge. The third method is to use conversation as a knowledge presentation method during the knowledge exchange because this technique can facilitate the evaluation of the reliability of knowledge and inspire new ideas.

The expectation of knowledge reuse is mainly about knowledge retrieval. The interviewees proposed three available methods of knowledge retrieval, namely, keywords, condition-based filter and category-based retrieval. However, no matter what retrieval method the expected BIM-based KM system adopts, such techniques should enable adaptation to the collaboration of different disciplines because of the lack of common knowledge among the different disciplines.

The interviewees also expect the system to consider using visualisation, simulation, clash detection and early analysis of BIM to support a proactive KM.

The interviewees also believe that the BIM-based KM should be combined with a few project management strategies, including asset information requirement (AIR), employer's information requirement (EIR) and soft landing (SL). AIR proposes the information to be captured and fed into the asset information model (AIM) for the O&M phase. In addition, AIR indicates the information needed by an organisation in relation to an asset. EIR will be developed based on AIR, in which the information required by a client for project development and operation will be specified. Additionally, the information provided in EIR will facilitate decision-making at each employer's decision point. SL is a strategy that emphasises the collaboration amongst design, construction and O&M. This strategy also emphasises post-project evaluation that can provide feedback for future projects, thereby facilitating knowledge reuse. Although AIR, EIR and SL are currently used only in the management of information level, if KM is combined with these project management strategies, or use AIR, EIR and SL as carriers of knowledge, then collaborative KM will be improved.

5. KM framework under the BIM environment for ECI and EFMI

The improvement of ECI and EFMI requires three aspects of support, namely, technical, cultural and process, based on the expectations of ECI and EFMI in the literature review and the results obtained from the interviews. The three aspects of the BIM-based KM for ECI and EFMI are not independent but complementary. Table 2 shows the details of the BIM-based KM framework for ECI and EFMI. Technical aspect includes knowledge sharing, capture, retention and reuse. Moreover, the six other technical requirements specifically aimed to aid early collaboration in design are management of tacit knowledge, proactive KM, knowledge adaptation, facilitation of common knowledge, responsibility allocation and knowledge presentation.

Table 2. The details of the BIM-based KM framework for ECI and EFMI

Elements of BIM-based KM framework	Mentioned by # of 30 interviewees	Number of quotes
Technical		
Knowledge sharing	21	66
Knowledge capture and retain	7	10
Knowledge reuse (retrieval and adaptation)	15	43
Tacit knowledge	5	12
Proactive KM	21	57
Common knowledge	7	9
Responsibility allocation	5	8
Knowledge presentation	22	44
Process		
AIR	9	10
EIR	16	29
SL	5	14
Knowledge transfer from project to organisation	1	1
Strategies for lack of participation	2	3
Cultural		
Relief of conflicts	3	3
Adaptation to change	12	12
Understanding of benefits of ECI and EFMI	10	14

The process aspect mainly considers the integration of AIR, EIR and SL into the environment of the BIM-based ECI and EFMI. The improvement of the process should also consider improving the traditional capture procedures to solve the lack of participation in post-project reviews or lessons-learned meetings. Moreover, the process aspect should consider how to transfer the knowledge of the project to the permanent part of the organisation.

Without a suitable cultural context, the expected BIM-based KM for collaboration in design will not have a good performance. The results of the literature review and interview analysis indicate that the cultural aspect of this BIM-based KM includes relief of conflicts, development of 'win-win' environment, adaptation to change and understanding of the benefits of ECI and EFMI.

6. Conclusion

This study mainly aims to explore the role of BIM in ECI and EFMI, as well as systematically summarise the existing KM status and challenges of ECI and EFMI through literature review. Thereafter, this research collected information through semi-structured interviews to explore the application of ECI and EFMI in real projects and the experts' views on BIM to improve KM. The interview also revealed the expectations of BIM-based KM for ECI and EFMI. In combination with the results of literature review and interviews, a KM framework under a BIM environment has been proposed and comprised three aspects, namely, technical, cultural and process. Overall, this study provides BIM-related research an idea that transforms BIM into building knowledge modelling (BKM).

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Leadership development in the South African construction industry

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Abstract

The construction industry is one of the major industry in South Africa, due to its positive infrastructure impact to the economy. Like any other industry, strong leadership is fundamental for its growth. Moreover, in order to stay competitive, South African construction organizations must find a way to train their project and construction managers to become capable leaders in their specific disciplines. Hence, this study presents findings on how managers can be developed into leaders in the South African construction industry. The data used in this research were derived from both primary and secondary sources. The secondary data was collected via a detailed review of related literature. The primary data was collected through a well-structured questionnaire aimed at 150 projects and construction managers in the South African construction industry. 110 questionnaires were received and data was analysed using Statkon SPSS software, whereby frequencies, MIS and descriptive were attained. Findings revealed that, curricula education and qualification can help develop leaders in the South African construction industry. Followed by leadership training courses, taking responsibility as mangers, and accepting new challenges were seen as important, in addition internal motivation, professional and personal development. The study presents a background about the construction industry and the importance of effective leadership in the construction industry for construction management performance.

Keywords:Construction leadership; Leadership development ; South Africa

1. Introduction

Leadership is one of the most critical elements for good project and construction management. The diverseness in activities and role players in the construction industry makes leadership more imperative, since leaders provide a directive or have influence on any organization or industry. Havenga [1] is of the view that, leaders inspire others to make decisions. Commonly, one can say that leadership is a process by which one person influences the thoughts, attitudes, and behaviors of others. South Africa, a country aggrieved by leadership challenges in different industries is always calling for leadership solutions. This always demands managers and entities to reinvent themselves or make way for new managers who are capable of being leaders in the construction industry. Good leadership helps our nation through times of challenges. It makes a business organization successful. It enables companies to fulfill its mission. On the contrary, the absence of leadership is equally dramatic in its effects. Without leadership, organizations move too slowly, stagnate, and lose their way [2]. With this background, leadership development becomes an integral aspect in developing managers into leaders in the construction industry. The paper gives clarity on leadership and leadership development in the South African construction industry, followed by presentation of the methodology and the findings before conclusions and recommendations are represented.

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2. Leadership in the construction industry

The principle of construction and project management is responsibility. This makes projects and construction managers vital to the development of any construction project. Not entirely stating that they do everything on a project. Conversely, it does imply that they have fundamental influence and responsibility on any project. Broadly analyzing the above we speak of leadership in the construction industry. Further, it is also apparent that the construction industry has a greater need for management and leadership understanding. Daft [3] stated that the complexity and the involvement of many team members in any construction project makes management and its leadership vital. Important in the sense that effective leadership is largely seen as one of the success factors in the construction industry [4]. In the study of leadership in construction, it is also important to note the distinct difference between leadership and management.

2.1. Leadership and the South African construction industry

The construction is a large-scale contributor of employment in South Africa and it also provides the physical infrastructure and it is the backbone for local economic activity. As an outcome, construction plays a fundamental role in the economic and social development of South Africa. Unfortunately, the legacy of apartheid has left the South African construction industry with a number of development and transformation challenges [5]. Limitations exist in the emerging sector with regards to the inability to access opportunities, finance and credit, as well as training with regard to leadership and management. Ofori [6] notes that the South African construction industry has been focused on management than in leadership. He further states that this orientation by South African construction firms and industry is resulting in a shortage of skillful ‘project leaders’ regardless of the large number of project managers produced. Ofori further stated that, low volume of leadership studies in the South African construction industry is due to the lack of knowledge of the industry on the part of social scientists and a lack of understanding of social sciences by those in the industry. However, in recent years, there has been an increasing appreciation of the significance of leadership and the role it plays in delivering effective construction projects. This growth of leadership in the construction industry has resulted in a slow but continuing increase in the number of publications on leadership and related topics [7]. The need for leadership and leadership development is undoubtedly of prominence in South Africa.

3. Leadership development in the construction industry

Bennis [8] noted that leadership development strategies are transitioning from the idea of teaching skills and competencies to teaching values and concepts. This immense shift is built on the idea that skills and competencies change from person to person, but the basic values and concepts are more common, leader to leader. Leadership development is driven by actionable information and individual accountability. As in the construction industry the construction environment has changed and it is more complicated, unstable and irregular [8]. Moreover, the skills needed for leadership have changed, more adaptive thinking abilities are of importance to the development of leaders in the construction industry. Methods of development haven’t changed much, Petrie [8] stated that majority of managers are developed from on the job experience, training, coaching and mentoring. Price [9] insinuated that the potential sources of leadership development include observing, mentoring or coaching by seniors, reading or self-study, education courses during university, education courses in college, company training, and job experience. In addition, Bogus and Rounds [10] stated that managers can be better leaders from self- education, attending seminars, reading, watching, experience, and from having active organizational mentors. As stated in the last South African section, there is no longer just a leadership challenge, it is a developmental challenge in connection with how do we develop as managers and leaders. It is also important to note that organizations are increasingly reliant on HR departments to build a leadership framework for managers capable of leading in the 21st century.

In supplement, Jarad [2] is of the view that construction organizations can develop leadership and management skills by developing a culture of teaching, mentoring, self-study, and frequent job changes. Companies can also use their own professional personnel to offer formal leadership and management training. Leadership development initiatives set the stage for organizational success by empowering employees to develop their skills and competencies. It improves retention, provides a foundation for succession planning and trains the next generation of leaders to focus on how managers lead, develop and partner with their employees.

3.1. Leadership development models

Leadership research history has different leadership development frameworks that have been developed and studied, below are some of this models;

3.1.1. Fiedler contingency model

Fred fielder [11] created this model in the 1960s, he studied personality and characteristics. This model focuses on leadership style and the situational context.

3.1.2. Navy leadership framework

Richardson [12], stated that this framework underpins from humility, courage and commitment. The framework teaches future leaders to inspire their teams and to be disciplined.

3.1.3. SHL leadership model

The model recognizes that leadership is a collective function with organizations. Bartram [13] created this model with an intention of presenting both transformational and transactional factors for leadership development.

3.1.4. Authentic Leadership model

Luthans and Avolio [14], created this model which focuses on self-awareness and self-regulations attributes. The model shows ethical behavior and relational transparency factors.

3.1.5. The Leadership Pipeline

Ram et al developed the model to answer the succession planning challenges for leadership development. The model integrates leader development at each managerial level within an organization.

3.2. Leadership development gaps

Looking at the different models above it is important to note that most of this models are done within the developed countries' context, that understanding can be seen as a gap for the development of leaders within the South African construction industry. Research studies on construction leadership development lacks models and frameworks that factor in situational awareness, ethical behaviours, technological understanding and having entrepreneurial ability [9]. Individual developmental measure from one stage to the next is usually driven by restrictions in the current stage of appreciative development. When you are challenged with increased difficulty and challenges that can't be reconciled with what you know and can do at your current level, you are pulled to take the next step [15]. In addition, development accelerates when people are able to identify the assumptions that are holding them at their current level of development and test their validity.

4. Research Methodology

Research methodology studies the background of the research and the anticipated results in order to achieve significant research outcomes. Moreover, the selection of an appropriate research design involves several steps, beginning with recognizing the problem, purpose of the study and in depth literature review. This research adopted a quantitative approach which involved the use of a questionnaire. It is also vital to note that the data used in this study were derived from both primary and secondary sources. Burns and Grove [16] describes quantitative research as a formal, systematic process that describes and test relationships and examines causes among variables. In addition, Polit and Hungler [17] were of the view that quantitative research is a survey to obtain information from a sample of people by means of self-report, whereby people respond to a sequence of questions posed to them by the researcher. The primary data was obtained through the survey method which used purposive sampling, while the secondary data was derived from the review of literature and archival records. The primary data was obtained through the use of a structured questionnaire survey. The questionnaire survey led to the compilation of the primary data. However, questionnaires were decided upon for this study for the following reasons: they require less time and energy to administer and they offer anonymity because the respondent's names are not required on the completed questionnaires. The format of the questionnaire had a section that identifies leadership development methods in the South African construction industry. Respondents had to select eminent methods that can be used for developing leaders in the construction industry, the selection was translated into frequencies and percentages and then ranked. This was distributed to a collective total of 150 projects and construction managers in the South African construction industry, Gauteng. It is vital to note that any research based on measurement must be concerned with the accuracy and dependability. A reliability coefficient demonstrates whether the test designer was correct in expecting a certain collection of items to yield interpretable statements about individual differences [18]. George and Shamas [19] notes that the value of the Cronbach's Alpha above 0.7 is acceptable for reliable analysis. Description of reliabilities of all scales used in the study indicated a Cronbach Alpha of above 0.7. The data presentation and analysis made use of frequency distributions and percentages of all the respondents.

5. Findings and Discussions

Findings from the 110 usable questionnaires revealed that 52% of the respondents were project managers and 48% of the respondents were construction managers. Furthermore, 69.5% of the respondents are currently involved in projects in the range 0-5 projects, 16.2% of the respondents are involved in projects in the range of 6-10.

5.1 *Methods and ways that develop leaders in the construction industry*

It is apparent from the table below that 89% of the respondents' said that education/skills and qualifications are important methods that can help with developing leaders in the South African construction industry. This factors were ranked first. Of the respondents 73% regarded leadership training courses as the second ranked method for leadership development; 72% selected taking responsibility (R=3) and 55% indicated new challenges (R=5). New experiences and financial benefits were ranked 8th and 9th respectively.

Given that at most instances it is employees and managers who market, create products, make decisions and sustain construction projects, the development of human resources is fundamental to the success of the global organization. Literature reviewed that leadership development is an unceasing, systematic process designed to expand the capacities and awareness of individuals, groups, and organizations in an effort to meet shared goals and objectives [20]. Jarad [2] was of the view that, the primary purpose of most leadership development interventions was to improve individual managerial skills and on-the-job performance. In addition, Jarad [2] stated that construction organizations can develop leadership skills by developing the culture of teaching, mentoring and being exposed to new challenges.

Table 1. Developing leaders in the construction industry

Ways to develop leaders in construction	N/%	Rank
Education / Skills / Qualifications	89% (N=97)	1
Leadership training courses	73%	2
Taking responsibility	72%	3
Learn new skills that enhances capability	56%	4
New challenges	55%	5
Inspirations from within the current leadership	54%	6
Clear guidelines or directions by current leadership	51%	7
New experiences	50%	8
Financial benefits, reward and incentives	42% (N=46)	9

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5.1 *Leadership development factors*

It is patent from the findings (see table 2 below) that internal motivation is required to develop yourself as a leader, this factor was ranked first with a mean score of 4.32; ongoing personal and professional development was ranked second with a mean score of 4.12; evident leadership skills was ranked third with a mean score of 4.11; succession planning and strategy was ranked fourth with a mean score of 4.10; and personal financial gains was ranked the least with a mean score of 3.63. Literature reviewed indicated that the first step in developing a leadership development strategy is to determine why the organisation believes that this is a strategy that should be pursued, in other words, what it hopes to achieve with the strategy, moreover leadership development initiative cannot be successful unless it clearly targets a specific business goal [9]. Bogus and Rounds [10] suggest that employees can be better leaders from self-education, attending seminars, reading, watching, experience, and from having active organizational mentors.

Table 2. Leadership development factors

Leadership development factors	Mean	Rank
Internal motivation is required to develop yourself as a leader.	4.32	1
Ongoing personal and professional development.	4.12	2
It is important for someone to demonstrate leadership skills in order to be promoted to a leadership position.	4.11	3
Succession planning and strategy.	4.10	4
It is important for a leader to have formal leadership training.	4.07	5
Personal gains have an impact on developing leaders.	3.63	6

6. Conclusions and further research

The study explored leadership development methods, ways and factors. The study revealed that there is a dire need to develop leadership skills of construction project leaders in the South African construction industry, this translated to be the main goal of this paper. Regardless of the fact that majority of the respondents agreed to having attended leadership development trainings, literature revealed that the development of leaders in the construction industry is a trip which requires fixed attention. Literature further revealed that leaders can be developed by self-education, attending leadership seminars, job experience, being coached and mentored. From the survey results obtained from the respondents, it was observed that education and qualification can help develop leaders in the construction industry. Followed by leadership training courses, taking responsibility, new challenges, internal motivation, professional and personal development, succession planning and strategy. It is worth noting that few respondents chose financial benefits as significant to helping them improve as a leader, yet companies use this as the most common way to retain and reward leaders. However, the research in the near future can focus on developing leadership development frameworks which are contextualized for the construction industry, this can be done by also providing a clear relationship between different methods and the developed frameworks.

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Measuring project risk management performance: a preliminary model

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Abstract

The function of project risk management (PRM) is to understand the uncertainty that surrounds a project and to identify the potential threats than can affect it as well as to know how to handle these risks in an appropriate way. Then, the measuring of the performance of PRM becomes an important concern, an issue not addressed yet in the research literature. It is necessary to know how successful is the application of the PRM process, and how capable is the process within the organization. Regarding construction projects, it is essential to know if the selected responses to mitigate or eliminate identified risks were suitable and well implemented. This paper presents a critical analysis of the relevance of measuring the performance of PRM and the benefits of doing so. Additionally, it presents a preliminary and pioneering methodology to measure the performance of PRM through the evaluation of the adequacy of the responses applied to mitigate risks, as well as to evaluate the resulting impacts as indicators of the effectiveness of these actions. This knowledge will allow construction companies to incorporate good practices, generate lessons learned, and thereby promote a continuous improvement of the whole PRM process.

Keywords: Performance; measurement; risk management; projects; key performance indicators.

1. Introduction

The construction industry faces major challenges in relation to the performance of its projects [1], [2]. Uncertainty accompanies globalization and technological advances, which can become risks in projects. If this situation occurs, these risks could produce impacts with negative consequences in the fulfilment of the objectives of projects, such as the cost, schedule, scope, and quality [3], [4], [5], [6]. For this reason, it is necessary to prevent the occurrence or being prepared with good mitigating responses if they occur, through an adequate management of risks.

However, no studies have been found so far with the focus on how to monitor and control the performance of risk management effectively. PRM is considered an activity of the planning stage of the project and there is a lack of post facto analysis of how it really worked. This paper raises the importance of addressing the issue of measuring the performance of risk management in construction projects, an issue not reported in the literature. It aims to establish a different perspective of risk management focused at the end of a project, and to evaluate what risks occurred, which ones were previously identified, what really happened with the risks that occurred, the impacts produced by them and how effective was the application of risk responses [7], [8].

The paper begins with a review of the literature, addressing the issues of how to evaluate the performance of risk management and why it is important to do this for construction projects. Subsequently, a brief description of the

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research and the model for PRM performance measurement are discussed in a preliminary manner. The paper ends with the conclusions and a brief discussion of following research stages to achieve the final objective of this study.

2. Literature Review

2.1. Performance measurement

Defined by [9], performance measurement is an instrument that helps to quantify the efficiency or effectiveness of an action, which provides information on what is happening regarding that action. Different organizational areas use performance measurement [10]. The main concern for many organizations is to achieve the strategic objectives defined by them, in addition to measuring the effectiveness of the established processes [11]. In order to achieve this, there are several approaches, such as the PMS (Performance Measurement System). This system defines key performance indicators or KPIs, which allow evaluating and measuring the achievement of objectives, identifying the type of measurements, establishing the mechanisms to obtain the data, describing and analyzing the results, and establishing the necessary actions that shall be made in order to improve [12], [13].

Among the most used tools for measuring performance is the Balanced Score Card, developed by Kaplan & Norton in 1993. Because of its ease of application and the information it provides, it is widely used among organizations. [14] adapted this tool to measure the performance of enterprise risk management in organizations.

Since organizations set strategic objectives, measuring their performance becomes a fundamental part of defining whether these objectives are being achieved. This is a permanent activity within organizations for closing gaps, identifying opportunities, establishing mechanisms to solve problems, and improving processes continuously. This is particularly important for those processes that are critical for the success of projects [15].

This paper is concerned with measuring the performance of one of these processes, project risk management, considered so important for construction projects. Given its relevance, it is important to understand the behavior of risks to try to handle them in an appropriate way in order to minimize their impact [2].

2.2. Risk Management

Given the current uncertainty and the recent global economic crisis of 2008, risk management has gained more importance and has revealed the deficiency of its application at both, organizational, and project level [16], [17]. Organizations such as the Project Management Institute (PMI), the International Organization for Standardization (ISO), and the Australia's Standards Organization as well as academics, professionals, experts, and governments, among others, have expressed their concerns about this issue. As a result, standards for its application, procedures, tools, techniques and some computing programs that support the application of risk management for a better functioning of enterprises and projects have been developed [2]. In general, the main operational concerns of risk management are on the following topics: 1) the identification of risks; 2) risk analysis and evaluation; 3) the development of techniques, tools and software that help with the application of risk management; and 4) the evaluation of the RM maturity within organizations [18], [19].

Several authors have investigated about risk and risk management, raising the interest from different industries and organizations [16], [20], [21], [22]. The risk management process includes five main stages [7], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33]. These stages are: 1) risk management planning; 2) risk identification; 3) risk analysis and evaluation; 4) response plan to risks; and 5) monitoring and control of risks. In addition, these stages can be divided into two main pillars: 1) identification and analysis, that includes the stages of risk management plan, risk identification and risk analysis and evaluation, and 2) responses and control, including the stages of response and monitoring plan and control [16], [34].

[16], [35], [2], note that the greater emphasis of the application of risk management has focused mainly on the risk identification and analysis stages. There is a lack of connection of these stages with the risk response plan and monitoring and control part producing a lack of knowledge about the effectiveness of the strategies to face risks and about the impacts of these strategies on project results.

In the construction industry, risk management is considered a bureaucratic and tedious activity usually applied only at the beginning of the life cycle of the project and merely regarding risk identification and analysis. The nature of projects that this industry carries out are usually characterized by a great deal of uncertainty and many restrictions of various kinds, which makes it necessary to try to identify as exhaustively as possible the risks that may arise and how they might impact the objectives. This activity should be part of the organizational culture permeating at all levels so

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that it can be incorporated into the project management and carried out throughout the life cycle of the project. At the end to evaluate how well the risk management performed, i.e., if responses were effective and what influence they had on project objectives [1], [2], [25].

This was evident in a survey conducted in 2013 by the KPMG, an international financial and taxation consultant based in Holland. It showed within its main results that risk management in the construction industry is one of the greatest challenges that companies and projects are facing, because it has prevented companies from having an adequate growth. It is also pointed out that the lack of the application of risk management causes projects with delays, which end up with a high over cost and a worn relationship with customers; it calls the attention that these same results were observed a decade earlier by the publication Re-Thinking Construction [36].

Then, besides what is described, it is stated in this paper that another cause of this situation is the lack of measurement of what happened during the realization of the project at its end or after, to find out if the risk management was effective or not. Then it is proposed that a methodology should be designed to achieve this purpose and that, with the information provided by the methodology, it would be possible to find out how PRM works really and obtain lessons learned for future projects.

3. Research Methodology

Thus, this research aims to propose a preliminary model for measuring PRM' performance. In order to do this, it was necessary to identify the key factors and variables that explain risk management performance. To achieve this, the following stages were carried out:

1) Literature review: various databases, scientific articles, and books were consulted. An attempt was made to identify if there is any model proposed to measure PRM performance and what would be the relevance of being able to do it. This review allowed the identification of key PRM concepts, the establishment of the existing gaps, and the creation of a frame of reference.
2) Development of a preliminary proposal of the performance measurement model: in this stage, risk management experts/practitioners were interviewed, being all of them persons involved in the construction industry, the insurance industry, or the academic world. Interviews were semi-structured, and main topics addressed were risk and uncertainty, risk management and the process of risk management based on its actual application to construction projects. In the second stage, key variables were defined and the preliminary model for the measurement of risk management performance in construction projects was constructed based on the application of risk responses.
3) Validation of the model: once the previous stage was completed, risk management experts and practitioners validated the model, the key performance indicators and its application through an analysis and evaluation.

4. Proposed model for project risk management performance measurement

It was possible to observe in the literature that there are deficiencies in the application of risk management in construction projects. Therefore, a series of interviews were conducted with experts on the subject and, from this point of view, conclusions were drawn on the relevant issues for a proper management of risks and the know how about how the industry really conceives and applies risk management in construction projects. In order to carry out these interviews, experts in the field of construction who work both in the academic and professional fields were consulted. The consultation also included experts involved in the area of insurance, which is an important subject for the realization of the construction projects.

Then, first, this approach looked for ways to measure the performance of PRM at the end of any project. In this way, to know how effective the risk management implementation was based on four principal factors: 1) Risk Identification Performance; 2) Risk Analysis and Evaluation Performance; 3) Risk Responses Performance; and 4) Risk Management Profitability.

How would this measure work? The goal of this type of measurement is to know how the implementation of risk management performed during the execution of the project. Then it is necessary to evaluate this performance at the end of the project using the variables that indicated in figure 1.

Fig. 1 Activities included in the PRM performance measurement.

As shown above, the key input variables for measuring PRM are the results of the following risk management activities: 1) Risk identification; 2) Risk evaluation; 3) Risk response plan; and 4) Implementation of risk responses when risks occurred. Then, at the finishing of the project, PRM performance is measured using the key performance indexes associated to a combination of these variables as shown in figure 2 and taking into account the four factors that were mentioned before.

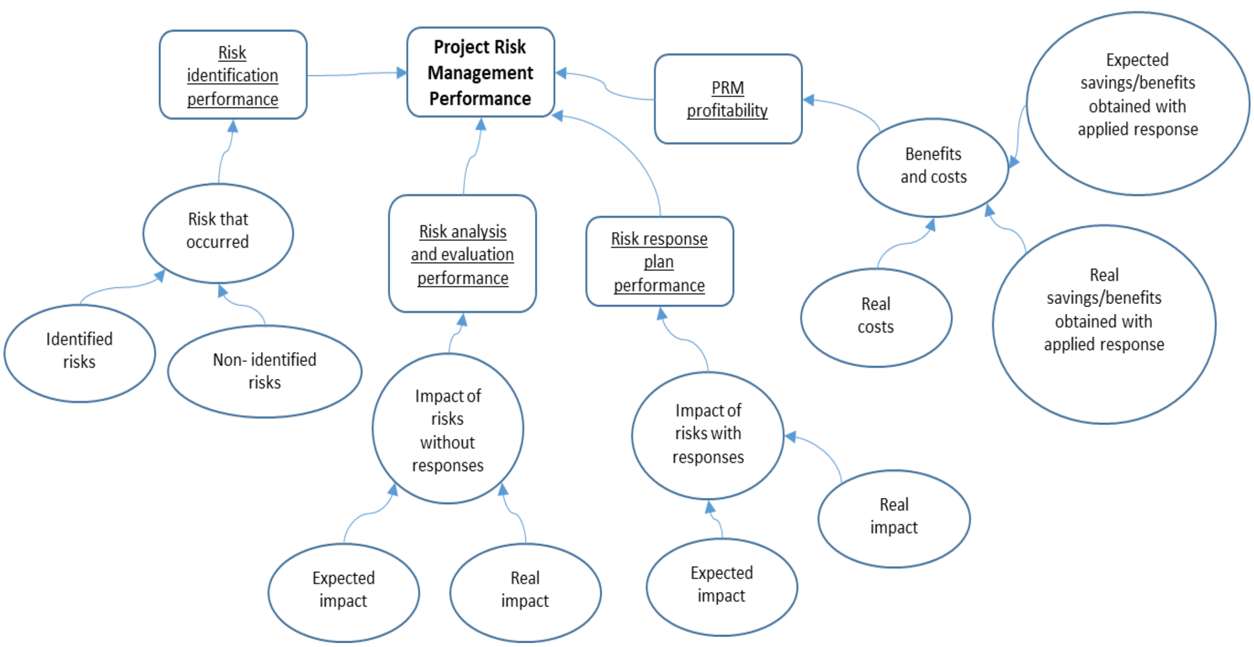

Fig. 2 Proposed model for measuring PRM performance.

5. Conclusions and Discussion

This article has presented an effort made to address a topic that has not been investigated largely according to what the literature indicates. The research has sought to obtain a model that correctly reflects the factors that are involved in the performance of risk management in projects, in order to use these factors to measure this performance. The model presented is still in the process of evaluation and adjustment, in order to make a definitive and proven proposal in a longer time.

It is expected that the measurement of the performance of risk management in construction projects will provide construction companies with a valid and practical knowledge of the behavior of this important function and that will allow to have valuable lessons learned to produce a substantial improvement of this management. Likewise, it is expected that this information could demonstrate the value of risk management in an industry that does not apply it systematically, suffering the consequences of this failure. If the medium and long-term objective is to improve the performance of construction projects with better compliance with their objectives, then risk management could be a lever of great impact in this regard.

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Opportunities and challenges in adopting higher strength reinforcement bars in reinforced concrete structures

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Abstract

The improvement in technology has enabled the strength of reinforcement bars to be progressively higher and a few developed nations have explored and embraced such changes in their construction industries. The paper outlines the opportunities and challenges faced by the Singapore construction industry in using a higher strength reinforcement. While the Eurocodes, the nation's design code, allows GR600 steel to be used, attempts to use to that strength limit have begun but there are still issues to be overcome before a wide spread acceptance and adoption can take place. Information from pilot projects on the use of such reinforcement shows that the benefits outweights the drawbacks.

Keywords: Reinforced concrete; steel reinforcement; high strength; challenges; opportunities

1. Introduction

The desire for taller and more complex strucures has led to the need for stronger and better construction material. The strength of concrete and steel has progressively improved over the years to meet this demand. However, the increase in the strength in concrete and steel also has its drawbacks and safety concerns. Design codes in different parts of the world have been revised and updated to cater for the design challenges poised by these new and stronger material. However, there are also significant advantageous and opportunities in adopting these new stronger material.

2. Benefits of higher strength reinforcement bars

The role of steel reinforcement bars in reinforced concrete structures is well known and as by increasing the strength of the steel, the direct economic gain can be significant. For example, by having smaller beam sizes from stronger steel reinforcement can result in floor height or a reduction in column sizes can increase the net usable (also probably rentable) space.

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The use of higher strength steel bars can also lead to reduction in amount of steel used and this has many benefits which translate in better construction productivity;

- Less congestions of steel bars which helps in improving the placing and compaction of concrete, hence better quality of casting
- Less amount of work thus cost for the preparation of the steel cages e.g. less cutting, less tying and less transport and handling

With a requirement of a higher transfer length between the higher steel bar and concrete, there is a tendency or need to use couplers and end anchorage accesories instead of lapping. This leads to less congestion of steel bars which adds to the improvement in construction productivity.

The reduction in the amount of steel reinforcement also helps in the Green and Sustainability initiatives for the construction industry.

3. Trends in different countries

In the United States Grade 100 (fy = 689 MPa) and Grade 120 (827 MPa) have been widely available nowadays in most states. These two grades have been introduced in ASTM A1035, Standard Specification for Deformed and Plain, Low-Carbon, Chromium, Steel Bars for Concrete Reinforcement since 2004 [1]. ACI ITG-6R-10 Design Guide for the Use of ASTM A1035/A1035M Grade 100 Steel Bars for Structural Concrete [2], provides recommended design provisions by which the higher yield strength is used to increase member flexural and axial strength.

High strength of thread bar SAS 670/800 (fy = 670 MPa) has been produced since 1999 in Hammerau (Germany). The use of this high strength rebar is not limited in Germany but has been used in other countries such as the New World Trade Center in New York, USA or the LotteCenter in Seoul, Korea [3]. An evaluation of this material for use with ACI code in the United States can be found in the report from the International Code Council Evaluation Services, ESR-1163 [4].

In Japan, high strength rebar USD 685 (fy = 685 MPa) was first used in 1993 for a 45-storey condominium [5] and since then it has been used widely in high rise construction in the country.

In Korea the high strength rebar grades SD600 and SD700 have been added to Korean standard KS D 3504 and the design code in 2012 has allowed the yield strength of rebar to increase from 550 MPa to 600 MPa [6].Currently big steel manufacturers including Hyundai Steel, Dongkuk steel in Korea supply both SD600 and SD700 in accordance with Korean standard KS D 3504.

In some projects, the use of high strength steel in applications also surpass the code recommendation; using bar diamaters of up to 75 mm and percentage of steel of up to 18% [7]

4. Adoption in Singapore

The Building and Construction Authority in Singapore has adopted the Eurocodes as the building design codes in 2013. Prior to change, BS8110 or CP65, its local adaptation, was the design code for reinforced concrete works where the highest strength for concrete and steel reinforcement were Grade 60 and GR500 respectively. The adoption of the Eurocodes has extended the upper limits to Grade 105 and GR600 respectively. There are many challenges and opportunities resulting from this change:

4.1. Regulatory Framework

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The quality of steel reinforcement depends on technology used and quality control of manufacturers. Singapore, being a free market and steel bars can imported from different sources around the world. It is very important to have stringent specification and quality control for rebars used in the country. The regulations require the Qualified Person (QP) who is the engineer responsible for the project to carry out essential tests on the materials used in the building works. Such tests are required to be carried out in a laboratory accredited for those tests. The QP can specify either BS4449 [8] or SS560: 2016 [9] as the standard for steel reinforcement in conjunction with the Eurocodes.

Mill certificates are not to be taken as proof that quality of material is acceptable. The number and frequency of tests are to be specified by QP in approved plans and specification to ensure the quality of rebar delivered to site confirm to the required standards. The QP is required to report to the authority if there is failure of the tests and to recommend remedial works. Unlike the steel of G500 or lower, the contractor or supplier proposing the use a higher strength Grade 600 rebar shall pre-consult the authority for the use of such rebars in any project prior to the use.

SS560 is a Singapore standard and it was revised in July 2016 to include the higher strength GR600 steel reinforcing bars to facilitate the construction industry to adopt and use GR600 rebars more widely in the local high-rise building and other construction projects. To ensure product conformity to the requirement, SS560 has stipulated a third party product certification scheme for such evaluation called the "Factory Production Control" or FPC certification. This conformity evaluation includes verification of standard properties, evaluation of test results and continuous surveillance of factory production control and audit testing. Steel reinforcment from sources without FPC certfication must be subjected to the material verification and routine quality control tests to ensure conformity.

In SS560, there are 3 different ductility classes –Class A, B and C for both the GR500 and GR600 rebars. Other than the change in yield strength of 600MPa, other mechanical properties are exactly the same as GR500. To facilitate the use of couplers, a new surface geometry called 'Threaded Ribs' has been introduced.

As to the site and quality control for GR600 rebars, it is not uncommon to have different grades of rebars used on the same project. Therefore, it is important for QP and site supervisors to have an effective site control system to differentiate and identify the right grade and ductility class. SS560 stipulates each reinforcing steel must have identification marks to identify the steel grade.

4.2. Key Challenges

- SS560 is only a product standard for rebars and but standard for other components in the rebar systems e.g. couplers, lock nuts or anchor plates are also to be specified.
- There are some concerns in the use of high strength steel reinforcement [10] e.g.
  - inability to fully utilise the potential strength of the high grade
  - may be more brittle
  - more cracking
  - more deflection
  - less effective as shear reinforcment
- Even though the Eurocodes permits the use of steel up to GR600, there is insufficient information or guidance or advice on its use. Hence, there is a need to have a design guide for the industry because the use of the higher strength steel is still new and the users are not familiar.
- Even though the SS560 has a FTC scheme to ensure the right material is used, the Singapore market is relatively small and many overseas mills refuse to meet such requirement. That limits the number of approved source of supply

4.3. Accesories e.g. Couplers

For almost 100 years, construction practices in the building of concrete structures have focused on the use of steel reinforcement to transfer tension and shear forces. The use of laps can be time consuming in terms of design and installation and can lead to greater congestion within the concrete because of the increased amount of rebar used. Reinforcing bar couplers available in the market have come across with a solution for this complexity as it provides a greater ease in design and construction of reinforced concrete and reduce the amount of reinforcement required. The strength of a mechanical splice is independent of the concrete in which it is located and will retain its strength despite loss of cover as a result of impact damage or seismic event. Force transfer mechanism of the coupler can be in different way: 100% mechanical, 100% chemical or a combination of mechnical and chemical. Different types of couplers are shown in Figure 1:

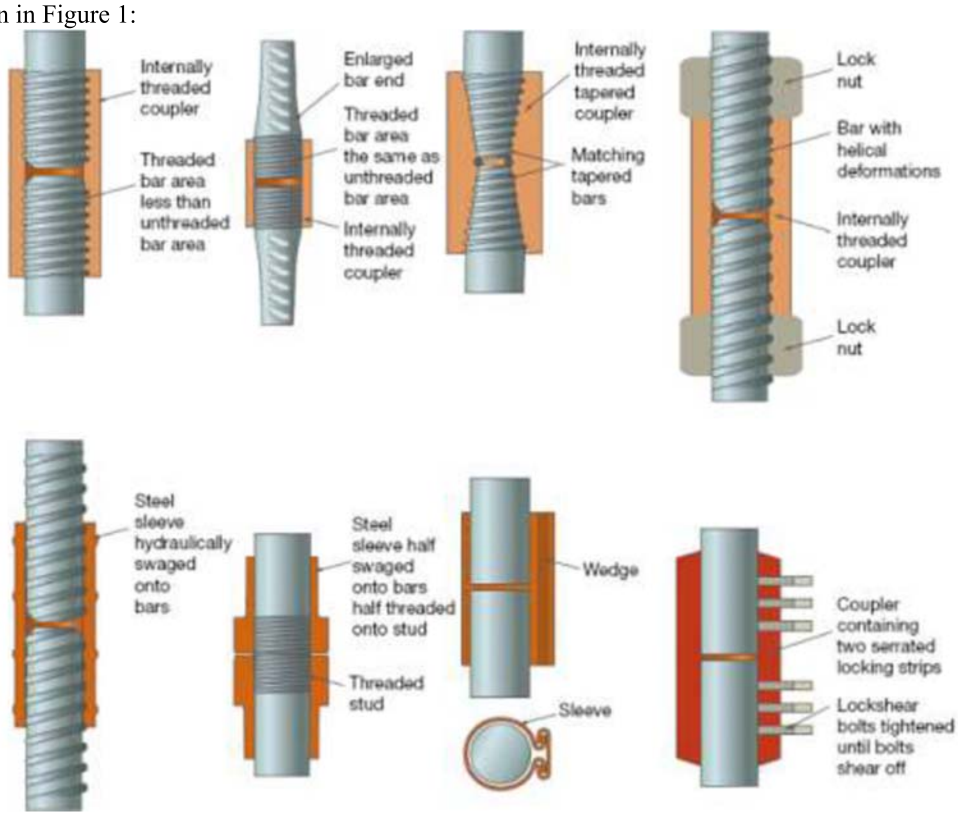

Figure 1 Different types of couplers

Currently, there is no stipulated standard in the regualtions on the use of couplers. However, the ISO 15835-1: 2009 & ISO 15835-2: 2009 [11] are suitable ones to be adopted. This standard has a similar "FPV" scheme for product conformity scheme but this would face the same challenges as the SS560 because of the size of the Singapore market. This two parts of the 2009 ISO are currently in the final stage of revision and will be released soon in three parts.

4.4. Pilot cases

Two projects explored to use the GR600 steel rebars as an alternative to the GR460 steel rebars. The results obtained are shown below :

- LTA Thomson East Coast Line T211 PJ [12]

In the project, GR600 TTK's threaded rebar and TTK's threaded rebar Joint System was proposed as an alternative design for parts of secant bored piles (SBP) walls in Thomson East Coast Line- Contract T211Project. • In the original design, one number of SBP comprised of 3 or 4 types of steel cage. Every rebar cage has different rebar arrangement depending on the design force. In the Alternative Design using higher strength steel with compatible coupler joint System, the reinforcement bar amount are reduced and thus its arrangement is revised to be uniform thoroughly all length of pile. As a result, the number of cages per pile is decreased from 3/4 cages to 2 cages. Figure 2 and 3 shows rebar arrangement of the original design using GR460 and alternative design using GR600 steel.

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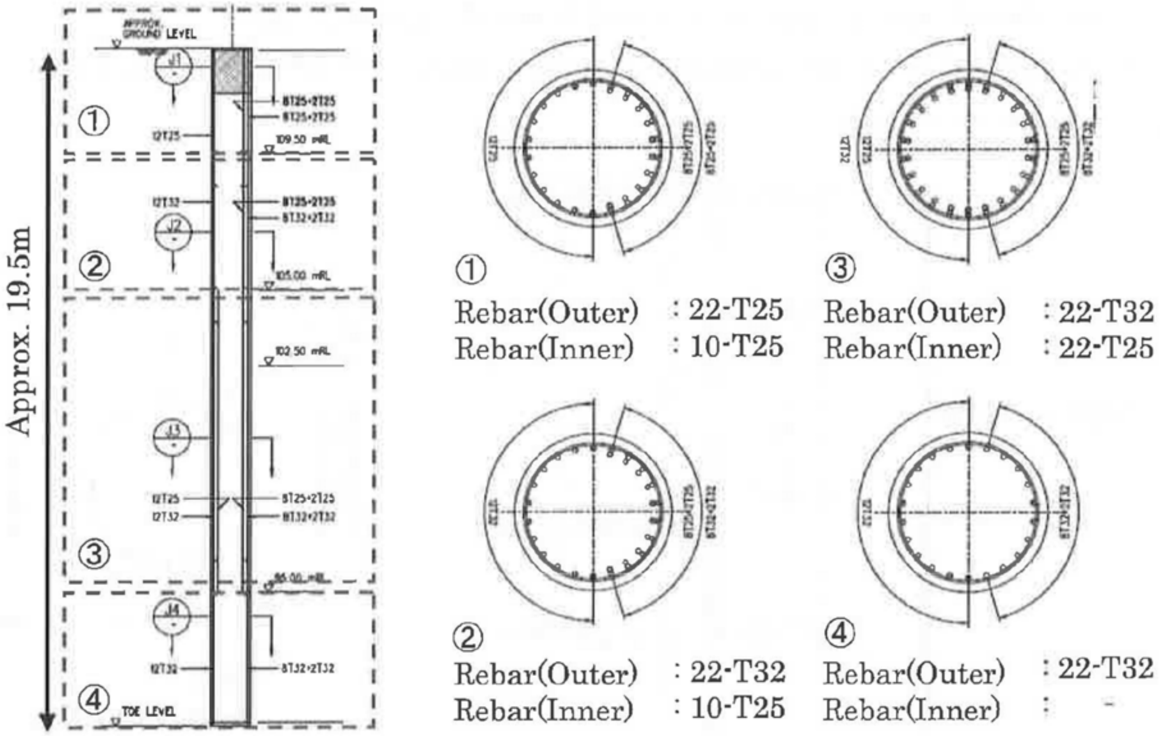

Figure-2. Typical rebar arrangement of original design(SBP-34C)

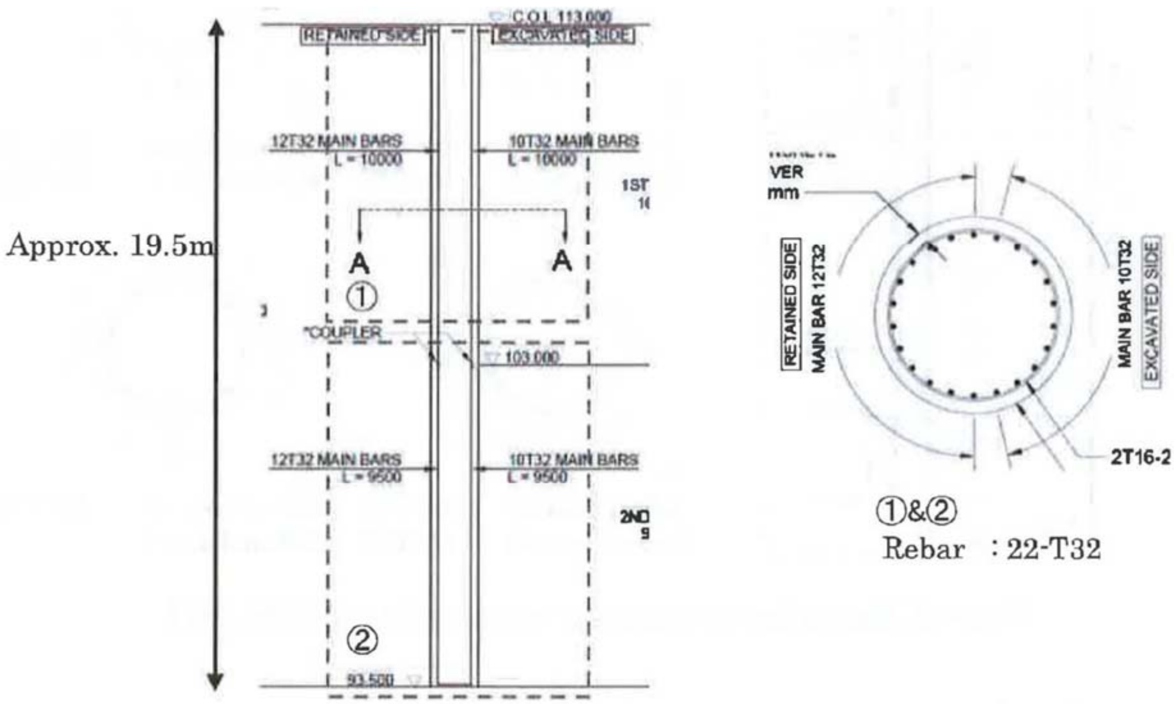

Figure-3 Typical rebar arrangement of the Alternative design (SBP-34C)

The benefits of adopting the alternative design using high grade reinforcement and compatible coupler system are described as follows:

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- Reduction of Rebar - Total reduction is 22.4% which consists of main rebar reduction of 11.6% and the overlapping bar saving of 10.7% by replacing with the coupler joint.
- Saving of Construction Time and Man-Hour - With the reduction in the rebar amount, not only the time spend for rebar fixing work on site is lesser, the prefabrication of rebar (cut, bend and caging) are also improved.
  - When the number of cages was reduced from the original 4cages/pile to 2cages/pile, the construction time was reduced from 200 to 100min/pile, thus 100mins (50%) was saved.
  - When the number of cages was reduced from the original 3cages/pile to 2cages/pile, the construction time was reduced from 140 to 100min/pile, thus 40mins (29%) was saved.
- Quality Improvement - With the reduction of the main rebar amount, the rebar spacing was increased and the congestion of bars was improved thereby also improving the concrete flow to the outside of the rebar cage during the casting and could therefore lead to better quality of the bored pile concrete. The less congestion of rebar arrangement will also help to ease of installation of anchor bars for the connection with RC slab structures. This also improved the productivity in both of pre-installed and post drilled anchor bars.
- Safety Improvement - Since the stiffness of the coupler is high enough to support the connecting prefabricated cage rigidly. Once the rebar cages are fixed by the couplers, there was no concern of falling-off/slippage of them due to failure of joint even before the joint grouting works.

Table 1 shows a sumary of the comparison between the original and alternative design

Items	The Original Design (Gr.460 with lap Joint)	The Alternative Design (Gr.600 with Coupler)	Reduction %
Rebar Q'ty/Fabrication	80.65 ton	62.62 ton	22%
Construction time 4 cages in original design	200 min /pile 12.0 man-hour / pile	100 min /pile 6.0 man-hour / pile	50%
Construction time 3 cages in original design	140 min /pile 8.3 man-hour / pile		29%
Quality	NA	Concrete flow is improved due to less congestion of bars	
Safety	NA	Prevent from joint slippage during cage installation	

- Tiong Seng Hub – a 9-storey General Industrial Factory Building

GR600 steel reinforcement was used for the columns, beams, slab and walls from 1st storey to the roof. From GR500 to G600 steel, there would be a 20% in steel amount from the higher strength but the average steel savings of about 15% was achieved (12% for the columns and 18%-20% for the beams and slabs). The unit cost of the GR600 steel was 20% higher than that of GR500. However, there is an improvement in the productivity and the manpower resulted in a saving of about 20%.

5. Conclusion

Higher strength steel reinforcement especially with high strength concrete allows stronger structures. The benefit of the saving in steel amount from the higher strength steel is currently offset by the higher unit cost. However, the lesser steel usage will lead to less manpower and transportation cost which is an important consideration in Singapore where construction productivity is one of the key concerns. In addition, there are also indirect benefits such as smaller members which in turn lead to more useable spaces. A reduction in the number of steel rebars and use of couplers also produce better quality of construction because of the elimination or reduction of congestion that prevents proper placing and compaction of concrete.

In spite of the benefits, the wide spread adoption of this higher strength rebars currently still face many challenges. The lack of familiarity in design using higher strength is hindering the use. A design guide will certainly be helpful in providing a better understanding of the issues such as gains as well as the limitations in pushing the boundaries. The need to ensure product conformity such as the FPC scheme can face practical problems for a relatively small small construction industry, especially so when the demand of the product at the early phase is still low. But this will improve when the demand increases. With the encouragement from the Authority, particularly on the productivity standpoint and when clients are more aware and receptive to this higher strength rebars, the usage is expected to popular with the normal strength counterparts.

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Opportunities for UAV's in Construction Planning, Performance and Contract Close-Out

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Abstract

Quadcopter drones and other unmanned autonomous vehicles (UAV's) have become common-place and their use is widespread among consumers and professionals in numerous industries. Aerial imagery and video can provide useful perspectives and have great value in communicating progress, for use in documentation of site activity and for use in marketing services. Drones, either through imagery or LIDAR, can further provide quick and accurate surveying information, which is valuable for positioning of facilities and activities. LIDAR data can also be used effectively for quality control and for quantity measurement. Imagery also has further applications in safety evaluation, productivity improvement, security and real-time job-site monitoring. Such additional uses have the potential for making a real impact on successful project delivery while increasing and competitiveness. Progressive construction companies and service providers throughout the globe recognize this potential and see significant promise for tangible return on investment. This paper will evaluate these opportunities for quadcopters and other UAV's based on experiences of the authors in using drones in Dubai and in the United States. The examination concludes with evaluation of the opportunities and avenues for research using UAV's.

Keywords: drones; uav's; construction; technology

1. Introduction

Unmanned aerial vehicles (UAV's), commonly known as drones, have become ubiquitous throughout the globe for hobbyists and within professional communities. Surveying and construction are one of notable profession where the integration of unmanned quadcopters have become commonplace over the last decade. Today, drones are frequently routinely employed somewhere in the delivery of a construction project along the life-cycle from concept through completion. This increase in the use of drones makes sense as resulting aerial imagery has great value in documenting, communicating and recording current conditions with visual perspectives previously unavailable without large expense. Considering just aerial imagery, the prevalence of drones makes sense at nearly all levels and for all participants in the project delivery process. Planners and designers can use aerial imagery in conceptual and preliminary design. Construction professionals can use imagery to layout construction sites and monitor job-site activity, owners can use likewise use the imagery for marketing and business development.

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To use drones for these purposes requires very little investment since low-priced commercial off-the-shelf quadcopter drones have sufficient photographic and video resolution and capture capabilities at high-definition or 4K resolutions. All that is required to implement such low-cost solutions is proficiency with drone operation and proper licensure, where and if such licensure is required. Many of these drones have become very easy to fly with drone software assisting with smooth flight operations. With these products, there is drastically increased availability of image and video-based information for construction project delivery. While video capability may be a primary attraction of drones, there are many other applications with remote sensing and delivery which could be explored. This examination will begin by looking at drones available for application in construction with a focus on low-cost quad and hexacopters, which have four and six propellers respectively. Known commercial or public-domain applications of drones will be summarized followed by examination of research activity for construction and across the project life-cycle. The examination will conclude with a discussion of opportunities for research and application of drones to improve construction project delivery.

2. Consumer and Commercial Drones

Unmanned aerial vehicles (UAV's) are widely used and commonplace in many different commercial industries, such as agriculture, surveying, forestry and ecology, and even in video game development. There are numerous manufacturers of UAV quad-copter drones that serve the needs of the commercial marketplace. Drones have different selling points, including range and flight time, carrying capacity and videographic/photographic capabilities. Examples of low-cost commercial drones for video capture by DJI, a leading consumer drone manufacturer, are shown in Figure 1. There are many other manufacturers selling consumer drones and other noteworthy providers of professional-level commercial drones and similar products may be found within the marketplace.

Figure 1: DJI Consumer Drones [source: DJI.com, accessed 04/29/2018]

Low cost drones come in many form-factors and with a wide variety of capabilities. Shown in Figure 1 are the Spark (a), Mavic Air (b), Mavic/Mavic Pro (c), and the Phantom 4 Series (d). These drones have differing camera resolutions, flight-times, sizes, and gimbal capabilities. The gimbal allows the camera to remain stable and somewhat isolated from the rotation of the drone. DJI Goggles shown in Figure 1(e) allow the user to incorporate the use of head-tracking technology and immerses the operator in the video being captured through dual screen projection.

Commercial Drones with increased power and size, increased flight times and ranges, and respectable flight load carrying capacity are available within the marketplace and being used within the industry. These drones are more powerful and faster thereby increasing the range and the amount of imagery that can be collected during a flight. Better batteries promise to increase the flying time further which would advance the capabilities of the drones for construction applications. Lifting capacities of larger quadcopter drones permit payloads that can further extend the application of the drone beyond photographic and video applications. For instance, aerial mounted LIDAR enables quadcopter drones to capture 3D laser scanning data and develop digital terrain models and digital elevation models. An example of an aerial mounted LIDAR unit is shown in Figure 2. Significant accuracy results when the approach is referenced to georeferenced control points. LIDAR and videography can also be implemented through fixed-wing drones, which would dramatically increase coverage area. Fixed wing drones have been found to be particularly useful for highway planning and programming given increased range and flight times. They will not be considered as part of this examination. Many of the techniques discussed for copter-drones could be equally applied to fixed wing drones.

Figure 2: Commercial Drone with Aerial Mounted LIDAR [source: Cargyrak, Wikimedia Commons, accessed 4/29/2018]

3. Uses and Applications of Drones in Construction

Cursory internet searches reveal a large number of commercial providers for drone base imagery and videography. There are numerous examples of aerial imagery provided on the web, which is typically presented to show and market drone services or to communicate information about a particular project in question. A typical image shows site progress and current status, such as that shown in Figure 3 depicting the current status of the construction of a school gymnasium at the end of March 2018.

Figure 3: Drone captured imagery of construction status [Source: Wikimedia Commons, March 2018]

Sites marketing the benefits of drone-based aerial imagery frequently provide rationale and discussion of opportunities for benefit of the approach throughout the project life-cycle. Opportunities discussed on various sites include:

- Construction progress photography and development of promotional and marketing materials – This could be for documenting progress or static imagery could be "turned into a time-lapse video or GIF' [1]
- Preconstruction planning and evaluation visual surveying of site terrain – "Before ground is broken and after it is cleared, you can get a detailed aerial view of the proposed construction site to use for logistics and production planning." [1]
- Visual inspection and auditing – With line-of-sight consumer drones, video can be live-streamed allowing real-time inspection of conditions on the job-site. This could be used as an effective tool to evaluate construction conditions in hard to reach areas to ensure quality and successful completion/progress of activities.
- Safety improvement – Drones can also be used to evaluate workers in hazardous areas removing the inspector from the hazardous area and providing frequent real-time feedback. This can mitigate risks and cut costs [2]
- Volumetric measurement – "using accurate aerial photogrammetry techniques, large areas (2D and 3D) can be measured to within CM accuracy. This can be accomplished quickly, cost effectively and with minimal disruption to the day to day workings of the site." [3]
- 3D Modeling – Drone based LIDAR can be used for developing digital terrain models and digital elevation models. Photogrammetry can also be utilized and a study on commercial drone industry trends revealed significant increases in the use of drones to develop 3D models. [4]

In 2015, a survey was performed by Navigant to evaluate applications of drones in the construction industry. The survey engaged the following with the percentage of respondents indicated in parenthesis: contractors (38%), construction managers (13%), owners/owner's reps (13%), architects/engineers (14%), and others (9%) or unspecified (13%). The survey asked participants to indicate which applications they would like to use a drone and the results are summarized in Table 1. Potential indicates the respondent's opinion on whether drones are useful the specified purpose in construction. Percent actual use indicates the percentage that the same respondents had actually employed drones. Of interest, for the applications specified, the majority of respondents (69%) also indicated that they would prefer to employ drones in-house rather than hire a commercial service. Also, when asked, the primary concern expressed by the respondents regarding implementation of the technologies was legal issues with 76.2% indicating that this was the primary or secondary concern holding back implementation. Privacy, learning curves and costs were not significant concerns of the respondents when considering issues that might preclude the implementation of drones. The Navigant report also indicated that, "[i]n the US, at the time of [the] report, the FAA rules on commercial use [of drones] are clearly holding back more widespread use." [5]

Table 1: Use of Drones by Construction Participants (Navigant Survey) [5]

Applications	% Potential	% Actual Use
Aerial photography to track job progress	92%	76%
Inspection of areas difficult or impossible to access	80%	59%
Aerial photography for marketing	74%	66%
Aerial photography for logistics and production planning	64%	45%
Safety monitoring and support	57%	28%
Land surveying, thermal imaging, laser scanning or other data collection	52%	26%
Transporting materials	15%	0%
Other	8%	10%

Tatum and Liu [6] discussed the implementation of drones recognizing the primary application, based on FAA authorized commercial exemptions, to be aerial photography and videography (65% of applications). Approximately 7% of the 1400 applications were for construction use, though it would be expected that a sizeable portion of use of drones in construction would be for aerial photography and videography. This is recognized by the authors whom summarize available literature and state that "[c]onstruction companies have primarily been using [drones] to provide real time reconnaissance of this jobsites and to provide high-definition (HD) video and still images for publicity and documentation of progress." [6, 7] Tatum and Liu discuss the use of the technology with respect to aerial photography, surveying, inspections and safety/security monitoring. To learn more about the commercial use of drones in the construction industry, a survey was conducted among construction professionals. For companies whom had used drones, 57% indicated that the drones provided cost advantage and 42% indicated that the drones provided positive schedule impacts [6]. The survey inquired as to the perceived risks of implementing drones. There was a small response rate to this question but the results were contrarian when compared to the Navigant survey. The "top four risks were identified [as] 1) the risk of crashing the [drone], 2) the risk of causing personal injury to the employee or civilians, 3) the risk of privacy concerns, and 4) the risk of causing property damage (either on the jobsite or on surrounding properties)." [6]

4. Current Research in the Use of Drones for Construction

Research activities on drones for construction were explored through a search of peer-reviewed journals and conferences. Ham, Han, Lin and Golparvar-Fard explored and summarized the use of drones for visual assessment and monitoring of civil infrastructure systems [8]. This study focused on reviewing methods that streamline "collection, analysis, visualization, and communication of the visual data captured," with a vision towards "automatic construction monitoring and civil infrastructure condition assessment." [8] The authors recognized image based approaches for progress monitoring, site monitoring, building inspection, building measurement, surveying and safety inspection. Published papers in each of these areas were identified and evaluated, data analytics available were summarized and the integration of the approaches with BIM were identified. The authors recognize that drones, "provide an unprecedented mechanism for inexpensive, easy, and quick documentation [but] … that there are still numerous open problems for further research." [8] This is especially true when trying to automate the use of the imagery and video collected.

Liu, et. al., [9] focused on the electromechanical systems and algorithms for mapping and image processing with a summary of civil engineering applications. Specific applications discussed including the use of UAV's for seismic risk assessment, transportation, construction management, and disaster response. For seismic risk assessment, through the new solutions the collection of building inventory data, enhanced efficiency of post-earthquake reconnaissance, and establishment of reliable seismic fragility databases for buildings and infrastructure. With disaster response, the authors discussed assessments, lifeline prioritization and information dissemination. For transportation, applications focused on real time traffic congestion mitigation. For construction, the authors focused on better decision making with enhance visual information, especially with respect to improved risk management. The authors also discussed the development and use of enhanced 3D models of the construction site.

Research papers have also explored the potential of drones of for construction safety [10], for mapping and earthquake response [11], for visual inspection in a wide-variety of applications, for security and materials management [12]. Researchers have also been exploring whether drones could be used to perform the construction activity itself. Of note is research performed in collaboration between Université catholique de Louvain (UCL) and the Massachusetts Institute of Technology (MIT) on masonry construction [13], which was shown to be viable and efficient given re-design of the masonry units.

5. Future Application and Research in the Use of Drones for Construction

In Tatum and Liu's survey, participants were asked to speculate as to future uses of drones. Responses included: "automated employee check-in/check-out, automated safety checks, scanning RFID tags on materials in laydown areas for inventory, material delivery, parts delivery, remote job walks, preview views from a building prior to construction, thermal scanning of utility scale PV plants, [and] interior missions." [6]. Dupont, et. al., explored the integration of UAV's with BIM as a method for improving construction productivity and identified coupled applications to integrate site imagery into the BIM model, to perform autonomous and regular monitoring of the construction site, and to automate construction tasks, especially through integration with autonomous construction vehicles. [14].

Certain applications for drones have already proven their effectiveness and have shown tangible return on investment. This include surveying applications, progress reports, imagery for communication among parties, and development of promotional and marketing materials. It would be expected that more drone activity would be seen for these purposes in the future. Site inspections are an obvious area where the use of drones will expand. Permitting a real time visual 'look' at conditions that might be difficult to get to or hazardous provides numerous benefits.

Research on image processing and automation will enable the development of automated inspections, which could have significant impact on quality and safety. Right now, the use of drones for inspection purposes is dependent upon personnel to examine the video; however, as research advances and automation increases, drone-based inspection will become more prevalent.

Survey respondents indicated that there is a use for remote job-site walks. Streaming a live-feed through virtual reality glasses provides a valuable tool for off-site professionals to 'experience' and 'see' the site conditions in a new way. This could be facilitated with the DJI goggles or with Oculus integrated through BIM with a connection to the drone video. It is expected that as the technology becomes more sophisticated and seamless, owners and architects/engineers may drive the use of such virtual walk through contract.

Scanning opportunities have been discussed in terms of LIDAR and research was identified that integrated drones with RFID's for inventory management and/or security application. Thermal imaging could also be employed on drones, which could be used effectively as a quality control tool. Drones and RFID tags could be used for tracking of any time of asset on the job-site, be it material, tools or even safety equipment worn by personnel. RFID clothing has already found a niche market outside of construction and could be employed to track personnel and correlate locations with work performance. This would ideally simplify productivity evaluation, which would provide useful real-time information for project control.

Material and parts delivery were indicated through the survey performed by Tatum and Liu as a future use for drones in construction. [6]. Retailers in the United States, such as Amazon, have been exploring the use of drones for package delivery. Government agencies in the United Arab Emirates have explored the use of drones for delivery of official documents. Drones have also been explored to rapidly deploy life-saving equipment, such as defibrillators, or medicine, such as Epinephrine/Epi-pens. The feasibility of using drones for delivery has been proven and extension to the construction site could provide benefit. For instance, drones could be implemented to delivery small tools and light-weight construction materials throughout a job-site.

Many of these uses for drones which have been discussed have already seen application in construction or a parallel industry, such as retail. Additional research is required to add capabilities, such as better automation or image processing. As the technology advances, it is expected that applications will become commonplace and the use of drones even more pervasive in the construction industry. The area with little real-time application at this point is the use of drones to perform the construction activity. It could be argued that such application is a complex form of material delivery; however, the challenge and the value is to re-think how the system can be developed to permit delivery and assembly in a fast and reliable matter. This has been shown to be effective through the research on masonry construction. Other applications could be explored and such approaches may have significant long-term impact on construction practice.

6. Conclusions

The examination began by recognizing the transformation that has occurred over the last decade of construction practice with respect the use of unmanned autonomous vehicles (UAV's) in construction, otherwise known as drones. Drones are ubiquitous and widely employed, most frequently, for capturing of imagery and videos regarding construction site conditions. The information is then used for wide variety of purposes, including but not limited to: planning, for site monitoring, for safety evaluation, for promotion and marketing, and for surveying. Drones can also be coupled with LIDAR for surveying purposes and the development of digital terrain models and digital elevation models. Thermal imaging cameras can also be employed for a variety of purposes, such as quality control. Photographic, video and live-stream data can further be used for monitoring, control, inspection and so on, when accessed and acted upon by experienced professional personnel. As research advances, more automation will be integrated and the technology will become more pervasive. For instance, image processing techniques can be used to automatically highly safety hazards and bring them to the attention of safety management personnel. Additional research will also continue to expand the reach and develop new ways to use drones, such as for time goes on, more natural hazard mitigation and for reconnaissance activities of existing buildings and sites. Applications developed for other industry, such as package delivery, will further have benefit for the construction industry which could make use of drones for small tool and light material delivery. But perhaps the most exciting application of the use of drones involves research being performed to integrate the drone into the actual physical activity construction, such as has been seen with the research on masonry construction. As creativity continues to expand, more construction processes can be redefined to employ drones for positive benefit in order to advance the industry.

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Optimizing Organizational Structures in Real Estate and Construction Management

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Abstract

Recent management issues are dominated by the term of efficiency. In particular, when it comes to projects in Real Estate and Construction Management, resources, namely time and budgets are running short. Thus, increasingly complex projects need nevertheless to be carried out in less time and on tight budgets. On this background, methods to optimize the consumption of goods and services are being developed using the given computational power on numerical techniques. These are based on the formulation of systems via the theory of systems or graphs down to a level where each variable is represented by an element and all interdependencies can be written as functions of all other variables. If one of the variables is declared to be optimized, a state-vector (set of parameters) can be found which matches the given demands respectively, absolutely or at least heuristically close to the optimal situation. Yet, all this rests on the fundament of a pre-set structure which is not subject to optimization but has a major influence. E.g. the predefined hierarchic setup of responsibilities allows only for a limited degree of optimization, while further development would possibly demand fundamental changes of the underlying structure. Only few optimization algorithms, e.g. derived from the traditional transport or assignment algorithms, address this situation by formulating all-encompassing structures where parameters represent the strictness of impact and are thus subject to structural optimization to some degree. In this paper we propose a set of criteria which allow to build truly sensible, i.e. optimized structures, before optimization methods with focus on parameters are applied to the system. Based on fundamental aspects like reduction of complexity, sensitivity towards modifications, stability and long-term behavior, optimization of structures instead of parameters will be available providing an appropriately predefined organization in particular for unique Real Estate and Construction Management projects.

Keywords: complexity; construction projects; hierarchical structures; optimization; real estate;

1. Principles of Optimizing Organizational Structures

Recent projects in Real Estate and Construction Management are becoming larger, therewith taking in more interacting participants, consuming more and more different resources, and are to be realized within shorter timeframes than ever before [13]. After long initial phases of design, planning, negotiation of permissions and optimizing procedures they are to be conducted flawlessly in shortest time and to produce no surprising events due to risky issues and in particular no repetitive loops [20, 27]. Thus, part of the preparation phase is to establish meticulously optimal structures, processes and parameters in order to ensure proper operation of the construction or development phase [18, 19]. Since careful preparation is under all circumstances much less costly than later reconsideration, special attention needs to be put on optimal design of the operation to come. In this paper optimization parameters for the organizational structures are to be derived and proposed for ad hoc use.

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1.1. General Remarks

Optimization methods are generally based on manually decomposing the complexity of a problem into a sensible structure. This is to be further broken down into finer structures where finally an element is composed by a single variable [7]. An accordingly well-formulated system can be described by the state-vector and the transfer-function of how a state affects the consecutive state [2, 10].

If one variable is declared a preference-value, respective algorithms are available to modify the system-state until the preference-value is optimized, i.e. maximized or minimized. So far, this can be achieved even under further boundary conditions at least by numerical approaches.

In particular, static systems may be optimized where no temporal development needs to be taken into account; namely the character of approaching optimal system-states plays no role. Dynamic systems may include time as an additional one-way developing variable. As long as the development can be determined by additional system-variables like the speed of modification or the strength of an assignment, e.g. as a definition of the character of controlling in force and latency, also dynamic aspects can be modelled and optimized.

Yet, this poses the problem that the structure of the system itself is not subject of the optimization consideration. However, exactly structures, e.g. regarding responsibilities, delegation, reporting and instructing as well as control loops, mainly define the stability of a system developing on the time axis. Thus the question arises of how structures may be optimized, possibly prior to parameter optimization.

Recent approaches work with sensible predefined organization types like trees and focus on finding minimal structures based on the goal to minimize the number of interfaces as these are expected to induce loss of information. Others propose principally specific structures as they avoid loops and therefore give no room to exponential or oscillating behavior. Some very classical approaches address the problem of optimal organizational structures by modelling all possible structures as complete graphs and optimize the degree of assignment as parameters on the structure. Examples would be the transportation problem or, as a derivative, the 1-0 assignment. It is common to them, that possible assignments need to be given manually and associated with cost. The algorithm may then make use of total or partial assignments due to an overall given optimization-parameter, e.g., under the precondition of finding a tree-structure, the optimal tree spanning a set of nodes can be found. Such is achieved by either randomly or systematically modifying the structure throughout the available space of states. Finally, evaluating for the best option reveals the preferred scenario.

The classical algorithm of Ford [9, 18] sorts given activities according to their rank and allows for no degrees of structural freedom. Neither loops nor ambiguities are permitted. Thus, two problems need to be solved: On the one hand, rank-loops are existing and lead to some well measurable fuzziness with respect to time. This may not impede the algorithms but should result in clearly given values. On the other hand, a multiple set of scenarios may be given and needs to be evaluated for optimal structures based on ambiguous relationships. Such are given e.g. by relationships forcing activities to be executed anytime, but not concurrently. By now they are modelled introducing an arbitrary sequence of one activity preceding the other, but based on no reason. So half of the scenarios are not investigated and need to be tackled by manual override.

The term "Optimization of structures" is widely understood as optimizing physical structures [20] where every volume elements is strongly impacted by the surrounding elements in contrast to organizational structures. One of the most promising approaches is based on bionic evolutionary methods. While iteratively checking for the distribution of strain and stress, some parts of the structure are growing, some are diminishing accordingly until an even distribution of loads and bearing forces is achieved. This approach corresponds to classical algorithms, e.g. derived from the transport or the assignment algorithms where all encompassing structures of maximum complexity are being subjected to optimization by rules of reducing the parameterized strength of an interaction until the criterion of optimization is met.

On this background the principle requirements to develop sensible organizational structures can be formulated. First of all, the structure needs to mirror reality and thus must not be restricted by algorithmic imperfections. This needs primarily to be observed when analyzing existing structures, e.g. company teams or markets. Yet, if systems ready to accomplish a task need to be constructed as in a project team, some restrictions of the structures are not so much introduced by the abilities of an algorithm but by the problem to be solved itself. In this case, criteria like complexity and stability come into play [23, 26, 28].

2. Principle View on Optimizing Structures

Optimal structures themselves are only in some very rare cases subject to the particular application, e.g. for legal issues. Mostly advantages or disadvantages of a structure are determined by the possible outcome of the behavior of the given system.

2.1. Behavior of a System

Let a general system be given as a set of interacting elements [2, 22, 29]: $\Omega = \left\{ n_i, k_j \middle| i = 1..N,\, j = 1..K,\, K \,\square\, N^{1+\alpha} \right\}$ Every element n_i may employ interdependencies to every other element [see e.g. 7] causing complex behavior which is described by a set of differential equations

$$n_i : \frac{\partial Q_i}{\partial t} = f_i(Q_r) \big| r = 1..N \qquad k_j : \left\{ (n_i \rightarrow n_r) \middle| i, r = 1..N \right\} \tag{1}$$

These are generally solved by complex exponential systems of the form [8, 23, 24]

$$Q_i = \sum_j g_{i,j} e^{\lambda_j t} \left(+ \sum_j g'_{i,j}\, e^{2\lambda_j t} + \ldots \right) \tag{2}$$

As a complex system is described by a set of linear differential equations where the solutions are complex exponential functions, the behavior is dominated by exponential escalation or oscillation. The share of exponentially decreasing variables is naturally low because the therefore required simplicity of a node referring mainly to itself with a negative coupling factor is rarely found. Nevertheless, such form the dissipative factors which are in general responsible for the stability of a system [29]. Thus, depending on the sign and value of the coupling parameters λ, solutions reflect a set of more or less strongly coupled oscillators where the behavior is known to be of chaotic character. Since the entirety of interdependencies, i.e. the “complexity”, represents the coupling parameters of the single differential equations, clearly the unpredictability of the system develops with complexity.

On this background, the terms and parameters of complexity need to be investigated in order to reflect on the sensibility of a given or constructed structure, in particular with regard to the sensitivity against modifications and time related development.

2.2. Parameters of Complexity

2.2.1. Heterogeneity

Homogeneous systems are represented by valid statistical momenta for e.g. in-degree or out-degree of nodes. Distributions are in particular given as e.g. Gaussian or Poissonian curves. In contrast, distributions with a heavy tail may be described by power laws $P(k) = ak^{-\gamma}$ [4]. Clearly, they cannot be represented by average values like the mean value or the variance if the exponent is small enough. Thus, the indicator of homogeneity, rsp. heterogeneity, is the exponent γ:

Heterogeneous: $\gamma < 2$ ($\nexists\, \bar{k}, \sigma^2$) Inbetween: $2 < \gamma < 3$ ($\exists\, \bar{k}, \nexists \sigma^2$) Homogeneous $3 < \gamma$ ($\exists\, \bar{k}, \sigma^2$)

In order to determine the strong heterogeneity limit, the mean value of the degree distribution is to be calculated

$$\bar{k} = \int_1^\infty k\, P(k) dk = \frac{a}{2-\gamma} \left(\infty^{2-\gamma} - 1 \right) \tag{3}$$

If $\gamma > 2$ the exponent becomes negative, leading to the first term to approach a very small value to a positive power, which is zero, while the second term remains one.

Thus, with $\gamma > 2$, the system is well represented by the mean value and thus called homogeneous. Otherwise, a system where $\gamma < 2$ would be characterized by a heavy tail indicated by $\bar{k} = \infty$ and be called heterogeneous. Establishing a weaker limit focusses on the determination of the second momentum (variance) which is

$$\sigma^2 = \int_0^\infty \left(k - \bar{k} \right)^2 P(k) dk \tag{4}$$

However, the term with the highest exponent under the integral will be of the type $k^2 P(k)dk$_leading to the same consideration with a given limit of $\gamma = 3$. In both cases, this does not imply that such values k, σ^2 are not existing, only, that they are not representing the given structure.

Remark: A large number of surveyed real systems is in fact exhibiting values close to the limit $2 < \gamma < 3$ [1, 12, 21]

2.2.2. Complexity

The term of complexity is widely understood only semantically, yet not defined mathematically. In particular needs to be distinguished whether a system is complex or merely complicated. According to [4] at least two criteria need to be met to establish complexity: A complex system shows heterogeneity over all scales and emergent behavior. Furthermore, as emergent behavior is limited by the characteristic of being not reducible [e.g. 10], complexity might be understood as property of a system which vanishes to some degree if reduced. Thus, complicated systems can be understood by reducing those to smaller (minimal) subsystems. Possible definitions of complexity which are completely compatible with each other are given here:

Complexity may be understood as the dimension of the configuration space of a project structure [25, 26]. Let the elements of a system fill the system volume and order these in a way that each interaction to another element is understood as a next neighbor interface. The dimension of the volume scaled to a maximum dimensionality of 1 can be written as $\alpha = \ln(\xi + 1) / \ln N = \ln(K / N + 1) / \ln N$, where N is the number of elements and K the number of interactions, possibly normalized and weighted.

Similarly, complexity represents the average entropy of a node in comparison to the possible entropy according to Shannon [17]: The average number of choices for a node to influence is $(\nu + 1)$ (av. edges incl. self), i.e. the number of real adjacent nodes, while the maximum number of choices, rsp. of adjacent nodes, is N (each node incl. self). Then the information content per node is: $E = \ln(\nu + 1)$ while the relative information content per node is: $E_R = \ln(\nu + 1) / \ln N = \alpha$. Finally, the entropy S as the expectation value is also:

$$S = -\sum p_i \ln p_i = \ln(\nu + 1) \tag{5}$$

Alternatively, the complexity α is given as the exponent of the structural development of a modification T from one layer r to the next $r+1$. Thus, it reflects the degree of the linearity of the structural development $T(r) \square \xi^{1+\alpha r} \Delta(\zeta) / (1 - \beta)$ with increasing structural steps r and the positive factor with each step $\omega \square \xi^{\alpha}$ [28].

Over all, the understanding of “Complexity” comprises both the value of α representing the average structural interdependency and the heterogeneity γ as an indicator of to which degree α is equally spread all over the system or concentrated to specific locations.

2.2.3. Recursiveness

Within iterative systems complexity is not only given by the number of interactions *vs* the available number of interactions but also by the repetitiveness of interactions to be utilized. Such is determined by the parameter of recursiveness, given by the number of (possibly weighted) paths leading from an element back to itself:

$$(1/N) Tr \sum_{m=1}^{\infty} A_{i,i}^{m} = \beta \tag{6}$$

where N is the number of elements and $A_{i,j}$ the normalized weighted adjacency matrix. The value β then represents the averaged percentage of an influence returning to the very same node. Thus, according to the understanding of complexity as the exponent of the development from step to step, repeated steps with a factor of β to the power of the index of the iteration needs to be considered:

$$Z_{i+1} = \xi^{\alpha} Z_i \quad \Rightarrow Z_{i+1} = \xi^{\alpha} Z_i \beta^0 + \xi^{\alpha} Z_i \beta^1 + \xi^{\alpha} Z_i \beta^2 + \ldots \quad = Z_i \xi^{\alpha} / (1 - \beta) \tag{7}$$

On this background the basic complexity α needs to be modified to include the effects of the recursiveness β:

$$\xi^{\alpha^{(R)}} = \xi^{\alpha} / (1 - \beta) \quad \Rightarrow \quad \alpha^{(R)} = \alpha - \ln(1 - \beta) / \ln \xi \tag{8}$$

Zero recursiveness leads therefore to no effect while higher recursiveness $\beta \leq 1$ leads to significant increase of complexity. In particular needs to be noted that the complexity possibly rises to values greater than unity since $\alpha = 1$ indicates the utilization of all possible interactions just once and not repeatedly.

Remark: Overall recursiveness obviously increases complexity as it possibly leads to unpredictable behavior. This is according to the higher degree of the differential equation system allowing for chaotic oscillation and escalating values. Therefore, the reaction of a system on modifications and the immediate as well as the long-term stability are mainly determined by recursiveness. Since in this context no general rules concerning the system can be given and the system is to be taken as it is, only avoiding high degrees of overall recursiveness can be recommended. Yet, as is discussed later, recursiveness can be used to reduce complexity by separation into smaller but complex systems of controlled units.

2.2.4. Combining Complexity and Heterogeneity

The aforementioned complexity is based on the average connectivity and needs to be considered in the light of heterogeneity:

With $\alpha = \ln(K/N+1)/\ln N = \ln(\bar{k}+1)/N$ and $\overline{k(\gamma)} = a/(\gamma-2) \quad \forall\gamma > 2$ we obtain

$$\alpha^{(H)} = \ln\left(\gamma\bar{k}/\left(\gamma-2\right)+1\right)\Big/\ln N \tag{9}$$

Clearly can be seen to which degree the parameter of complexity becomes distorted with rising heterogeneity and reaches large values when approaching the limit of $\gamma \to 2$.

2.3. Reducing Complexity

According to the meteorologist Edward Lorenz [14], who originally introduced the understanding of chaotic behavior, exactly the term of "complexity" is defined as the property which leads to unpredictable behavior of systems. Concluded reversely, complex systems need to be avoided in order to achieve controllable systems. Generally spoken, reducing complexity is a means to make a system more predictable as it simplifies its behavior [6, 11]. Using any of the given definitions of complexity, the concept of separability allows to understand this in more detail.

2.3.1. Concept of Separability

The tendency of breaking up a system into a set of independent superimposable units is no new understanding and has been formulated within the context of several situations [3, 5]. E.g., the RNM-algorithm (Random Neighborhood Method [15]) is used to identify independent subnetworks within a network in order to treat them independently and finally superimpose their outcome. Also, the principle of division of work follows the same idea. A set of work to be done is assigned to different units as independent tasks but this is to be paid with an increase of coordination effort and expenses [16]. As previously pointed out, complexity may be defined amongst other concepts by the increase of the consequences of a fault travelling through a network. Avoiding such cumulation is accomplished by shortening the length of the developing chains, i.e. separating the range where a fault may have consequences [26].

2.3.2. Formal Approach on Separability

Local **complexity**, defined as $\alpha = \ln(\xi+1)/\ln N \quad \xi = K/N$ [26] is understood as the relative entropy of a node as a share of the maximum local entropy $\ln N$. Using the same understanding, the possible entropy S of a total system allowing each element to equally influence any other element needs to be investigated in order to understand the effects of separability. The entropy of a total system is:

$$S = \sum_N \ln(N-1) = N\ln(N-1) \tag{10}$$

If a system is separable, i.e. can be divided into two distinct subsystems, the possible interaction within the systems is reduced to a given fraction while the remaining overall interaction of the two subsystems is linear, i.e. additive. Assuming separation into subsystems of equal size each for illustration purposes, we obtain the entropy as a function of the number z of subsystems. The first term refers to the entropy of the N/z subsystems while the second term mirrors the entropy of the newly interacting subsystems.

$$S = -(N/z)\ln\left(z/N\right) - z\ln\left(1/z\right) \tag{11}$$

The minimum is given by the balance of reducing the entropy of the subsystems with size but increasing entropy with the rising number of still interacting subsystems: $0 = \left(\partial/\partial z\right)S \Rightarrow z_{\min} = \sqrt{N}$.

The degree of **recursiveness** is also reduced by separation into smaller subsystems since a significant number of loops is cut down to smaller loops with the subsystems or fewer loops through interdependencies between subsystems. Assumedly let the recursiveness utilize the complete volume of the system, i.e. the interactions distributed over the volume. If z subsystems are separated, the number of interactions available for recursiveness decreases accordingly: $\beta^{(unsep)} \sim N\left(N+1\right)$ and $\beta^{(sep)} \sim \left(N/z\right)\left(\left(N/z\right)+1\right)+2z\left(z-1\right)$ Since N and z are expected to be large numbers we obtain furthermore: $\beta^{(unsep)} \approx N^2$ and $\beta^{(sep)} \approx \left(N^2/z^2\right) + 2z^2$. The minimum of the ratio $\beta^{(sep)}/\beta^{(unsep)}$ yields the optimal separation with respect to recursiveness, provided beta being not zero and leads to: $z_{\min} = \sqrt{N}/\sqrt[4]{2}$

In addition to this consideration of the overall recursiveness, the *local* recursiveness remains to be discussed: The difference would be in particular that in a very local environment no more recursiveness leading to chaotic behavior needs to be taken into account, but the recursive parameters can be analyzed and in most cases constructed in a positively utilizable way. The optimal substructure thus would be to localize recursiveness absolutely, i.e. restricted to a set of only two mutually interacting elements where the outcome can be safely dissipating ($\lambda < 0$) and therefore with $\beta^{(local)} >> 0$ contribute starkly to stabilizing the whole system.

The issue of **heterogeneity** yields no optimum in terms of numbers since all these considerations refer to an average situation which is not given with non-homogeneous systems. Therefore, the optimum state to be achieved would be a homogeneous network in general. Introducing subsystems not only has the effect of separating independent sections but also helps to understand the smaller subsystems as they *demand* to be more comprehensible allowing to treat them separately. This will only be the case if they are no more required to be understood as average behavior but as a well understood mechanism. So, the concept of heterogeneity becomes obsolete within the sections. This leaves the requirement of having to choose the separation so that the heterogeneity of the reduced system - comprising and thus interfacing the subsystems - is much lower and the overall situation becomes homogenous.

2.4. Examples and Case Studies

In many situations heuristic methods already utilize the principle of separability.

2.4.1. Anti-Rigidity Measures: Time-floats and Fuzzy Logic

Wherever complex systems need to be understood and solved, a large number of conditions for a limited number of variables needs to be met. The heuristic methods traditionally introduce approaches to weaken the conditions. In network plans the rule of using the maximum required time distance when optimizing project durations is set. Obviously being not optimal, this proceeding at least solves the contradiction of relationships aiming at a single node. Furthermore, deliberately time-floats (to be distinguished from time-floats resulting from the given relationships) are positioned in order to decouple sections of the network plan allowing delays not to pass transitions [9, 18]. The same methods are applied on production volumes introducing safety margins and overproduction. Similarly, modelling interactions as fuzzy variables weakens the strict rules of interaction in order to allow for a solvable overall system, which may be slightly or strongly contradictory otherwise.

Case Study: If a set of 10 subsequent processes each following an Erlang (r=16) duration distribution where the average duration is 5 days and the variance is $\sigma = 1.25$ the coupling is strong, thus $\alpha = \ln(10/10+1)/\ln(10) = 0.3$ Introducing float times of 1 day between the subsequent processes reduces coupling from 45.1% to 21.2% i.e. from 100% right hand overtime risk to 47% overtime risk. Therewith, the resulting complexity is reduced to $\alpha = \ln(0,47+1)/\ln(10) = 0.167$ while a float time of 2 days leads to only $\alpha = \ln(0,15+1)/\ln(10) = 0.06$.

2.4.2. Network Plan

A network plan being the set of activities to be consistently positioned on the time-axis is artificially restricted to being loop-less ($\beta = 0$) and thus restricted regarding its complexity. This is required based on the argument of mapping logical sequences to ranks where the cause always lies on a lower rank than the consequence. Then loops cannot exist and even if solved by iteration a worst case maximum of *N* iteration runs of *N* steps each is required to assign each node the correct rank value. Classical algorithms such as FORD [9, 18] rely on this fact.

The average complexity approach allows estimating the average effort to $\xi = N^{\alpha} - 1$ steps per *N* worst case runs where heterogeneity plays no significant role. Yet, if nodes to be calculated are picked randomly the effort rises nonlinearly with the center of gravity of the high degree nodes sitting more towards the start in contrast to the end of the causal chain. Taking the extended complexity $\alpha^{(H)} = \ln\left(\gamma\xi/(\gamma-2)+1\right)/\ln N$ and therefrom $N^{\alpha^{(H)}} = \gamma\xi/(\gamma-2)+1$ as the speed of propagation of changes through the network, at least the increase of effort can be estimated to $A = N\xi \Rightarrow A = \gamma N\xi\left(\gamma-2\right)$. Besides constant factors this is $N\xi$ for large values of γ proportional to *N* as before, but rises to infinity with γ approaching the value of 2.

Yet, reflecting real situations circular references are indeed possible, e.g. representing the same factual relationship seen from two or more different perspectives redundantly. If known, they could be eliminated, but if not, they lead to an infinite number of iteration runs and therewith infinite results when calculating causal ranks. If iterating positions on the time-axis instead the results will be finite since redundant interdependencies lead to the same result and thus a

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stabilizing situation. Even more, slightly contradictory instructions lead to a virtually stable situation as the system may oscillate with low amplitudes around the fuzzy solution correctly indicating the slightly undefined true position on the time axis [e.g. 9, 18, 19, 25]. In this case, $\beta \neq 0$ is required but at the same time the parameters λ inevitably need to be real and negative or at least, if complex, leading to oscillation with a strongly limited amplitude. Since this is not always the case such systems pose the challenge to be designed carefully in order to exhibit long-term stable behavior.

Case Study: A most simple strictly linear network clearly fulfills the requirement of being a loop-less network. With a given number of e.g. 50 activities each directly following the other we have: $\beta = 0$, $\gamma = \infty$ and thus $\alpha = \alpha^H = \ln((50-1)/50+1)/\ln(50) = 0.17$. This can only be simplified by further reducing the number of members of the given chain of activities. If the activities were arranged as a completely parallel set we obtain $\alpha = \ln((50-2+50-2)/50+1)/\ln(50) = 0.27$. However, the strong central pooling node leads to a starkly inhomogeneous system $\gamma \approx 1$ where $\alpha^{(H)} = \infty$ becomes virtually infinite and no sensible statements can be issued.

2.4.3. Tree-Structures

Classical tree-structures are constructed in a similar way, introducing artificial restrictions in order to simplify the behavior. In particular, the requirements of being loop-less and of unambiguous unidirectional paths from each node to the singular source-node are effectuating limited complexity [5, 28]. This induces some principle incompleteness since the characteristic variable to branch on is reduced to merely a single one which does not correspond to reality. Yet, separability is made use of, based on the assumption that sub-nodes are only cooperating via the single super-node and do not have other interrelations.

The recursiveness $\beta = 0$ clearly keeps the system small and predictable, unidirectional paths furthermore ensure short and clear lines of impact, be it responsibility and instructions (towards the leaves of a tree) or reports (towards the root). The fundamental complexity is given by the algorithms of finding the least spanning tree, where each node is connected by as few interactions as possible, implying $\xi = K/N \text{ minimal} \Rightarrow \alpha = \ln(\xi+1)/\ln N \text{ minimal}$.
Extending this, the parameter of heterogeneity allows to optimize tree-structures furthermore leading to the plain rule of employing nodes with a similar span of responsibility. For example, if exactly μ nodes are connected to each super-node and l levels of hierarchy are present, the number of nodes will be in total

$$N(i) = \mu^i \quad N = \sum_{i=0..l} \mu^i = \left(\mu^{l-1}-1\right)/\left(\mu-1\right) \quad \textit{and} \quad K = N-1 \tag{12}$$

The number of connections is $K = N-1$ since each node is connected to exactly one super-node except the top-node itself. Counting downward yields the same value due to the closed character of the graph. With $\xi = K/N = (N-1)/N$ the fundamental complexity is fairly small for larger systems $\alpha = \ln\left((N-1)/N+1\right)/\ln N \approx \ln 2/\ln N$. Any deviation from a constant responsibility span μ changes not much of the structure itself but leads to rising heterogeneity which should be avoided. This is only a very minor requirement since a tree-structure is already reduced to an optimal shape as far as possible.

Case Study: Let a tree-structure represent the responsibility for certain units, e.g. $N = 50$. Since responsibility can neither be operated in loops, nor can deal with double paths, the tree is the only available structure leading to the parameters $\beta = 0$, $\gamma = \infty$, $\alpha = \alpha^H = \ln 2/\ln 50 = 0.17$. However the physical decomposition of a building would follow a similar tree-structure with the same parameters, but the constructor would be forced to limit the numerous existing interactions of the elements to the few options permitted by the tree.

2.4.4. Control-loops

Inherent dependencies, e.g. the necessity of construction parts to fit, are traditionally not implemented in maps of the system but defined by design ("Gestaltungsplanung") [27]. Thus, they are expected to be fulfilled without further activity. Yet, this dependency is still given and the interaction is active and possibly turns out to be crucial if not matching perfectly. On this background, a fairly complex system is treated in a starkly simplified manner by merely ignoring the given complexity.

On the one hand, treating the complete system accordingly would present the correct parameters of complexity, heterogeneity and recursiveness. On the other hand, methods are required to construct the system in a way which maintains the expected simplicity. This is accomplished by the introduction of control-loops. Additional elements (so-called "control processes") are introduced besides each critical element ensuring the accuracy of particular variables within the given margins. Therewith the strong dependency of the consuming node on the quality of the providing node is completely broken, the system largely decoupled into numerous fairly small independent subsystems. This is valid as long as the resources required to ensure the controlling are not coupled themselves and add another

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dependency. Based on the strength of the controlling units additional effects like the stabilizing behavior and the time constants to stabilize the result come into play [26]. The subsystems tend to behave like coupled oscillators, where the transfer of oscillations through the network needs to be observed very carefully. Furthermore, fast oscillations are introduced by fast regulators leading to the necessity of damping the behavior by low-pass filtering of the network, i.e. dissipation by cumulating local values and thus a lower reaction time.

If all possible interactions of a complex system were separated by introducing *N* additional control-loops, the resulting system may be treated as a new system comprising *N* pairs of elements being perfectly controlled and held at constantly fitting values. Thus, the local $\beta \gg 0$ are highly recursive but due to the very local character of the loops well dampened and under control. Then, all interactions of the remaining system would vanish at least to a degree of control η ranging in $[0..1]$, the heterogeneity would be unchanged as well as the inherent β. Only the number of (=sum of weighted) interactions would be reduced by a factor of η while probably an additional number of $N\eta$ interactions would appear due to the dependency of the required resources for each control loop on the total effort. With $K^{(C)} = K(1-\eta) + N\eta = K + (N-K)\eta$ we obtain $\alpha^{(C)} = \ln\left((1+\xi)+(1-\xi)\eta\right)/\ln N$. In total, mainly independent of ξ, a control degree of about $\eta \approx 0,9$ is required to bring the complexity down to 50%. In particular needs to be denoted that there is no minimum detectable indicating complete control to be the optimal improvement to a system.

Case Study: A set of 100 tightly interacting elements with $\xi = 3$ leads to $\beta = 0$ $\gamma = \infty$ and therewith to complexity $\alpha = \ln(300/100+1)/\ln(100) = 0.3$. Introducing additional control elements for each value adds another 100 supervising elements and two further interactions each for control. Thus, we obtain a new value of complexity which does not change much: $\alpha = \ln((300+2\cdot 100)/(100+100)+1)/\ln(100+100) = 0.23$. However high recursiveness is introduced since the control elements refer to the controlled elements and vice versa leading possibly to $\beta = 1$ where $\alpha^{(H)}$ escalates. Yet, it is known (since the construction of control requires this to be so), that the respective exponents λ are strictly negative, the subsystems formed by an element plus the controlling element comprise all the respective recursiveness and can be treated as completely stable subsystems safely providing the given values. Thus, the system formed by the stable subsystems is no more dependent and we obtain vanishing complexity: $\alpha = \ln((300\cdot 0)/(100)+1)/\ln(100) = 0$

3. Conclusion

Organizational structures, e.g. for a Real Estate or Construction project, cannot be predefined in general but need to be set up according to the given situation.

On the one hand, the situation is determined e.g. by a social or technical environment, a market, a specific method or task, or a structure inherited from the past. Then, a meticulous analysis is required to understand and predict its future behavior as are actions, performance and conduct. In terms of systems theory this is its general stability and sensitivity behavior based not so much on details but on central parameters like complexity, heterogeneity and recursiveness proposed here. This will principally allow judging the value or risk of any engagement to the given situation or project and enable to make proposals of improvement. At least critical hotspots of the project can be detected easily and special attention directed to these which may turn out to be crucial for large and tightly constructed projects.

On the other hand, systems, i.e. organizations, are unique to each project and therefore to be constructed explicitly for the particular needs. Since projects are defined to be non-recurrent and non-repetitive, exactly the fitting organization is required to cover the risks of unknown variables and situations by its ability to treat them positively and therewith lead the project to success. Thus, risk management is the property of an organization to become independent of lacking specific knowledge of particular variables. Therefore, parameters like complexity, heterogeneity and recursiveness are the basis for any estimation of the sensibility of the organization towards changes of variables and determine the behavior, i.e. the stability of the crucial results. Thus, organization structures need to be constructed with a particular focus on such parameters and optimized with respect to these prior to being set in operation.

In short, we propose, based on the formal proof of the heuristically well known rules that any organization or structure must be exhibit the least possible complexity $\alpha, \alpha^{(C)}, \alpha^{(R)}, \alpha^{(H)}$, which can be achieved by constructing as many subsystems as possible, mainly independent from each other and subjected to strong local controlling mechanisms, where again resources need to be independent of each other. Only after this, classical optimization methods may be applied to the given system without the need to reconfigure fundamental pre-settings.

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Organizational culture and stakeholder success criteria in construction projects

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Abstract

This paper presents the findings of a theoretical investigation into the association between organizational culture and stakeholder management. With an aspect focused on international construction projects, the study explores the relationship between the cultural origin of key stakeholders and the cultural context in which projects are realized. Emphasis is placed on the examination of project outcomes and the factors that influence cultural domain. Secondary data suggests stakeholder management and corporate culture are critical areas that decide an organization's success. The importance of these areas will inevitably grow in the future as projects continue to be procured in a global economy. Identifiable theoretical associations between the constructs have been found that provide early evidence that stakeholders and culture influence project life-cycles. Stakeholders—organizations and their representatives—must be informed of the distinct types of cultures and success criteria to ensure they manage them efficiently alongside traditional and long-accepted project variables.

Keywords: critical success factor; construction project; organizational culture; stakeholder management.

1. Introduction

In recent years, construction project management has attracted enormous global interest, especially in organizational culture and stakeholder management. These two independent social constructs are crucial for successful construction project management, hence the need to explore the relationship that exists between them.

In his often-cited textbook, Walker [1] explains that construction project management (CPM) has been recognized as a distinct profession for a long time, yet, in the long-established context of natural and social scientific knowledge discovery, the study of how projects are organized and managed has, relatively speaking, evaded the attention of academics. Walker goes on to say, in a somewhat defiant manner, that 'management is the dynamic input that makes the organization work' [1]. Aaltonen *et al.* [2] sharpen the focus of Walker's viewpoint by explaining that the management of stakeholders' needs and requirements is an essential consideration for teams managing complex, global projects. More specifically from the perspective of the construction industry, several studies have pronounced that stakeholder involvement is an essential organizational component when realizing successful project outcomes (see example [1-3]). Recognition that stakeholder management is a fundamental aspect with regard to construction project success has understandably grown in recent years [4].

Ankrah and Proverbs [5] have acknowledged that organizational culture is an inherent aspect of a project's environment and that a definitive empirically-based interpretation of it is currently lacking. Eberlein [6] expands this position by explaining that culture is a critical factor that contributes to the realization of successful project management outcomes. Because large projects typically involve many stakeholders, each with competing values and demands, Marrewijk and Smits [7] have remarked they are potentially *conflict-ridden* environments. Driven by the need to gain a deeper, more meaningful understanding of organizational culture, Hofstede *et al.* [8] present five dimensions that can be used for exploring *culture awareness*. They explained that managers could choose to use these dimensions to regulate the social conflict that may arise within a project environment.

Currently, borders no longer limit construction and infrastructure projects. In fact, large-scale construction projects have increased the business opportunities available for global construction firms. These global construction projects involve managing culturally-diverse and globally-dispersed teams, international financing, and more importantly, global stakeholders. Considering the above findings, the aim of this paper is to present the outcomes of a literature survey to find the association between organizational culture and stakeholder success criteria (see Fig. 1). This has resulted in the need to develop a conceptual, theoretical framework that illustrates the variables and steps that contribute to the management of successful construction projects in culturally-complex contexts.

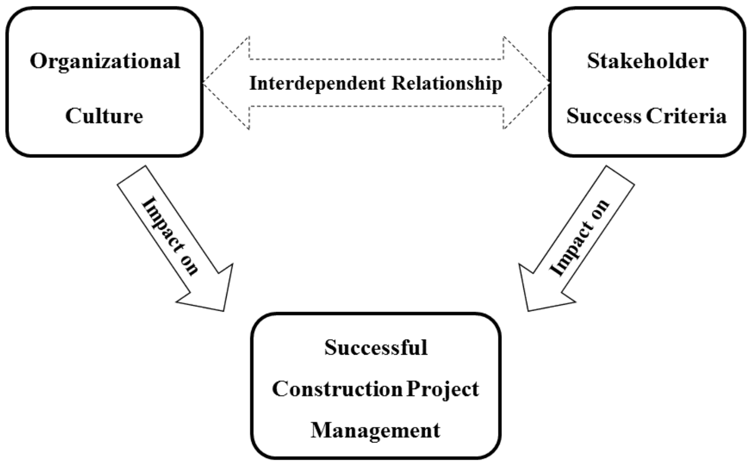

Fig. 1. Core elements of successful construction project management

2. Project success

According to the Oxford English Dictionary [9], success is defined as 'the accomplishment of an aim or purpose'. Young [10] defined success from managers' personal views as 'those words that conjure up a picture we paint in our minds' and he provided examples of these pictures: huge benefits gained, public recognition, great achievements, and promotion to new projects. This takes the point-of-view of the managers or leaders themselves. Müller and Turner [11] defined success criteria for projects as 'the measures by which we judge the successful outcome of a project; these are dependent variables which measure project success'. This introduces the concept that the project outcome is the measure of project success. Furthermore, APM [12] defined success as 'the satisfaction of stakeholder needs, which is measured by the success criteria as identified and agreed at the start of the project'. The word *success* used in earlier definitions shows that it is dependent on some elements, like stakeholders, clients, sponsors, managers, resources, project team members, organizational culture. Moreover, each one of these elements can measure the success or failure of the project [10].

In general, the presented various authors' perspectives on project success definition agree that there must be some form of measure by which a project is judged to be either successful or not. The most common element in these definitions is the acknowledgement that projects have some level of complexity that involves different elements including the two core elements—stakeholder management and organizational culture—which are the focus of this study.

3. Stakeholder management

Stakeholder, as a lemma, first appeared in the domain of management literature in an internal memorandum at the Stanford Research Institute—now SRI International, Inc.—in 1963 where it was used to define ancillary support groups [13]. Aaltonen *et al.* [2] discovered that for almost every publication about stakeholders that exists, a new definition is proclaimed. Of the many examples, a contemporary yet classic definition is offered by Friedman and Miles who have pronounced it as ‘any group or individual who can affect or is affected by the achievement of the organization’s objectives’[14].

According to Friedman and Miles [14], there are many publications that present different theories about stakeholders. For example, Phillips, Freeman, and Wicks have added that ‘one of stakeholder theory’s greatest strengths is also one of its most prominent theoretical liabilities . . .’ and go on to define stakeholder theory as ‘a theory of organizational management and ethics’ [15]. In addition, Meding *et al.* [3] have mentioned the importance of fully embracing stakeholder theories in construction projects due to the increase of stakeholders’ diversity, power, and influence. However, Smyth [16], as cited by Meding *et al.* [3], discussed the utilitarian approach, which bases the value of a firm in terms of profit and growth. He suggested the need for ethics and relationship management principles to bridge the conceptual gap in this theory to help manage stakeholders in practice. In summary, studies mentioned in this paper have recognized stakeholders to have a considerable effect on project outcomes and acknowledge the need to manage this relationship with stakeholders successfully. This means considering some common factors such as stakeholders’ characteristics and dynamics, relationship and communication with stakeholders, understanding engagement and needs, and defining the link between stakeholders and project success.

On the other hand, according to Rockart [17], critical success factors (CSFs) ‘are, for any business, the limited number of areas in which results, if they are satisfactory, will ensure successful competitive performance for the organization. They are the few key areas where ‘things must go right’ for the business to flourish. If results in these areas are not adequate, the organization's efforts for the period will be less than desired’. Likewise, Yang *et al.* [18] have said that understanding stakeholders related factors are essential during the project process to establish appropriate decision-making strategies. These perspectives highlight the importance for managers to acknowledge CSFs. However, Jepsen and Eskerod [19] found in their study that stakeholder identification, classification, and analysis are essential factors for stakeholder management. Olander and Landin [20] recommended four CSFs for stakeholder management, which included analysis of stakeholders, communication, evaluation, and relationship.

So far, this paper has identified and discussed the fundamental theories explaining (1) stakeholder management and project success and (2) stakeholders’ CSFs, both of which included consideration of the management of communication with stakeholders. Most of the factors discussed are essential to delivering successful projects. However, most of the authors have focused on finding the factors without ranking them or creating models to manage them.

Molwus [21], in his doctoral thesis about stakeholder management in construction projects, has developed Yang *et al.* [22] model that helps managers to identify and manage stakeholders CSFs and ranked 15 CSFs according to priority by building a model for 5 main CSFs groups for the management of stakeholders in construction projects. Molwus’s model not only named the 5 main stakeholder factors that have been highlighted in past studies but also substantiated the indicators for each factor; thus, making it easier for makers to apply the knowledge and manage stakeholders successfully (see Table 1). For these reasons, this study uses these CSFs for stakeholder management in order to identify the CSFs of the selected project.

4. Organisational culture

Cameron and Freeman [23] mentioned that the correct management of organizational culture leads to delivery of successful projects; this directed scholars in the management field to improve and develop different methods to help with the management of organizational culture. There has also been an abundance of research on organizational culture and its associated disciplines: this has resulted in many meanings and explanations of organizational culture and its relevance to other organizational parameters (Ankrah and Proverbs [5], Smircich [24], Zu *et al.* [25]).

One study was carried out by Schein [26] during which he defined organizational culture as ‘a pattern of basic assumptions, invented, discovered, or developed by a given group as it learns to cope with its problem of external adoption and internal integration that has worked well enough to be considered valid and therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems’. According to Marcoulides and Heck [27], organizational culture is a complex phenomenon characterized by many dimensions. One reason for the many dimensions that have been described is that organizational culture is very general and inclusive in scope [28]. However, Hofstede *et al.* [8] strongly argue that the cultural values of each organization need to be explicitly identified, and that reliance on reported values and beliefs from, for example, a parent company in one region may not be a reliable measure of the culture of a subsidiary in another region. This implies that changes in stakeholders, and their inherent cultures, will have an impact on the potential organizational culture of projects.

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From the theoretical perspectives of organizational culture, Smircich [24] mentioned that many scholars had linked the concept of culture with the study of organization management but every organization theory had been studied from a different perspective in terms of the way it manages interdependencies and exchanges across system boundaries. For example, some scholars have studied organization and culture from a practical and operational perspective, while others have studied a *rules* or *scripts* perspective, while others have focused on one or more concepts of culture related to the organization, including cognitive, symbolic, structural, and psychodynamic perspectives.

Table 1. Critical success factors groups for stakeholder management [21].

Constructs	Indicators
Stakeholder characteristics and project characteristics (SCPC)	• Clearly formulating the project mission; • Ensuring the use of a favorable procurement method; • Carefully identifying and listing the project stakeholders; • Ensuring flexible project organization; • Identifying and understanding stakeholders' areas of interests in the project.
Stakeholder analysis (SA)	• Determining and assessing the power (capacity to influence the actions of other stakeholders); urgency (degree to which stakeholders' claims requires immediate attention); legitimacy (perceived validity of claims); and proximity (level of association or closeness with the project) of stakeholders; • Appropriately classifying stakeholders according to their attributes/characteristics; • Predicting and mapping stakeholders' behaviors (supportive, opposition, neutral etc.); • Predicting stakeholders' potential influence on each other; • Predicting stakeholders' potential influence on the project; • Identifying and analyzing possible conflicts and coalitions among stakeholders;
Stakeholder dynamics (SD)	• Resolving conflicts among stakeholders effectively; • Managing the change of stakeholders' interests; • Managing the change of stakeholders' influence; • Managing the change of relationship among stakeholders; • Managing change of stakeholders' attributes; • Managing how project decisions affect stakeholders; • Predicting stakeholders' likely reactions for implementing project decisions.
Stakeholder engagement/empowerment (SE)	• Involving relevant stakeholders to redefine (refine) project mission; • Formulating appropriate strategies to manage/engage different stakeholders; • Keeping and promoting positive relationships among the stakeholders; • Communicating with stakeholders properly and frequently (instituting feedback mechanisms); • Considering corporate social responsibilities (paying attention to economic, legal, environmental and ethical issues).
Project Success (PS)	• Completion of project on time; • Completion on budget; • Completion to specified standards/qualities; • Completion to the satisfaction of a majority of the project stakeholders.

Furthermore, many methods and frameworks have been designed to identify and measure organizational culture. In this context, Wallach [29] developed a set of cultural dimensions based upon a synthesis of other major organizational culture indices. Another method is the Organizational Culture Profile Scale that was developed by O'Reilly *et al.* [30]. The third is the Competing Values Framework (CVF) that was developed by Quinn and Rohrbaugh [31], and the fourth and final one is the Organizational Value Congruence Scale that was developed by Fitz-Enz [32] and Fitz-Enz [33].

This research will focus on CVF as a model to explain and recognize the differences of organizational culture types. Zu *et al.* [25] have argued that the CVF developed by Quinn and his associates explores the deep structures of organizational culture relating to compliance, motives, leadership, decision-making, effectiveness, and organizational forms in the organization [31]. Yeung *et al.* [34] added that the CVF could be integrated into the organizational culture to other organizational components, which are both theoretically and psychometrically sound. Furthermore, CVF is built on two axes to explain the differences of value orientations. The axes are (X+Y) and are derived from the control-flexibility axis (vertical) reflecting the extent to which an organization focuses on change and stability. A focus on flexibility shows the organization's desire for flexibility and spontaneity, while a focus on control indicates a mutual desire to stay stable, controlled, and in order (see Fig. 2).

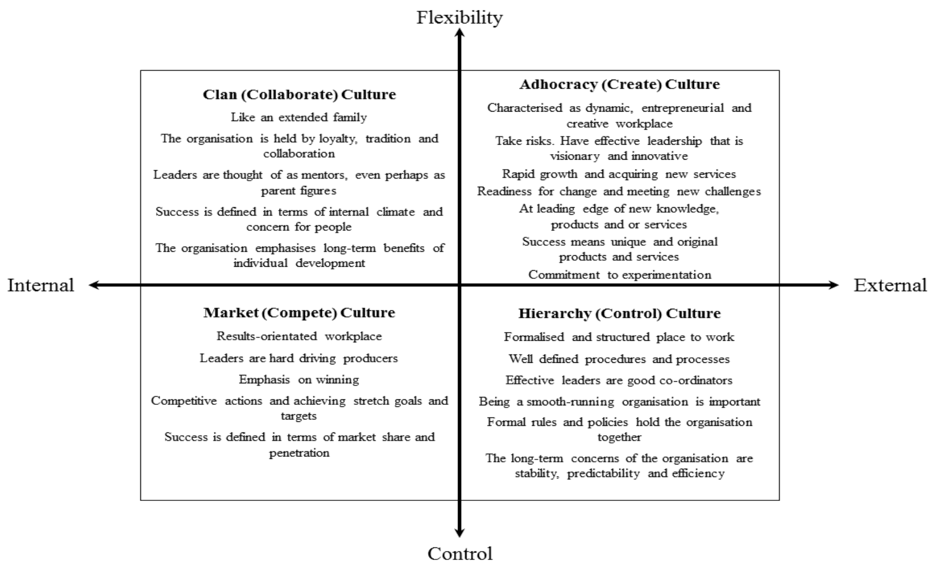

Fig. 2. Competing Values Framework [28]

Ajmal and Koskinen [35], however, mentioned that if managers understand the norms of organizational culture about the *right* and *wrong* and manage it correctly, it will lead to the successful operation of organizations. Likewise, Ashkanasy *et al.* [36] have suggested that an awareness of culture types within the organization from the strategic phase of project life cycle is essential to recognize the project organization environment and beliefs that will reduce conflicts. Ankrah and Proverbs [5] mentioned that organizational culture in construction projects consider the characteristics, tactics, competencies, goals, and values of the project environment. Therefore, recognizing the type of project organizational culture is essential to improve project delivery.

In addition, the earlier literature of organizational culture and project success shows a healthy relationship between these two elements. It revealed that identifying and understanding the types of culture within the project reduces conflicts, promotes innovation that eventually leads to improved project delivery. It also defines the link between organizational culture and successful project management. Although the above-reviewed literature has defined the impact of organizational culture on project management success, as well as established the impact of stakeholder management on project management success, there is no apparent literature discussing the relationship between organizational culture and stakeholder management explicitly. If both organizational culture and stakeholder management impact the success or failure of project management, then it is logical to say that there must be some connection between the two. This study, therefore, intends to look at this undefined relationship with the aim of enhancing the tools currently available for improving construction project management.

5. Research design

The research process started with a review of the literature on stakeholder management and organizational culture. A construction project as the subject of the case study will be selected based on the following criteria: service provider classified as a global provider for construction projects, the location of the project outside the home base of the service provider (another state, country, or region), and a construction project considered successful. Based on the survey of

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literature, the research focus was set, and a questionnaire has been structured for data collection using both the competitive value framework (CVF) instrument to identify the organizational culture of the chosen project, and the stakeholder criteria for stakeholder management [21, 22] to identify the stakeholders criteria of the chosen project. A web-based method has been selected to administer the electronic survey questionnaire.

The target respondents of the survey questionnaire will be the decision makers of the selected project: managers, directors, operations managers, quality managers (both internal and external stakeholders related to construction projects), public and private clients, project professionals (in-house and out-house), and contractors and suppliers, as identified by Chinyio and Olomolaiye [37]. Moreover, Structural Equation Modelling (SEM) will be utilized to explore the associations between the constructs constituting the two variables: organizational culture and stakeholder success criteria.

4. Discussion

The literature on stakeholder management shows the importance of recognizing and identifying the critical success factors to help managers deliver successful projects. Likewise, many scholars have mentioned the CSFs of stakeholder management within construction projects. Some have identified the CSFs constructs [19, 37], while others have identified the CSFs indicators [3, 18, 22]. Yang *et al.* [22] investigated CSFs from both sides and ranked them from the most influential to the least. More recently, Molwus [21] grouped the CSFs into five main constructs by converging the theories about stakeholder management and the outcomes arising from empirical studies.

Organizational culture theories link culture and organization projects to clarify the types of cultures in each organization. The organizational culture literature also shows how vital it is for managers to understand the types of culture in which a project is being delivered. Many theories that described culture have been presented in the literature [24, 26, 27] and many authors have empirically examined these theories [29, 30]. However, Cameron and Quinn's [28] competitive value framework (CVF) has been used to underpin many types of research because it shows that it is both a theoretically and psychometrically sound instrument when integrating and operationalizing organizational culture with other organizational components [25, 28, 34].

The initial examination has led to the hypothesis that the CSFs for stakeholder management in construction projects by Molwus [21] has an association with organizational culture (see Fig. 3). For example, stakeholder characteristics and project characteristics (SCPC) indicators—ensuring flexible project organization and use of a favourable procurement method—can be linked with the CVF's adhocracy culture; while SCPC indicators, such as, formulating the project mission and identifying the project interest and stakeholders, are more likely associated with the CVF's hierarchy culture.

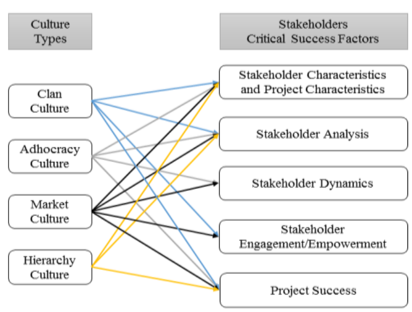

Fig. 3. Illustrated relationship between organizational culture and stakeholder CSFs

The stakeholder analysis (SA) indicator—determining and assessing the power, urgency, legitimacy, and proximity to stakeholders—shows an association exists with CVF's four culture types. The third construct, stakeholder dynamics (SD) as a whole, is more closely related to *market* and *adhocracy* cultures and, to a lesser degree, to *clan* culture. The stakeholder engagement/empowerment (SE) construct, however, is more likely to be related to *market* and *clan* cultures. The last construct, project success (PS), shows a link with all the organization types.

6. Conclusion

The above indicative literature review shows that both stakeholder management and organizational culture have an impact on project success. To examine the relationship between organizational culture and stakeholder success criteria for a successful construction project and to develop the indicators with the literary theories to classify the relationship between the two variants, it will be necessary to test Molwus's [21] model (see Table 1) and Cameron and Quinn's [28] CVF model (see Fig. 2).

The discussion section of this paper evaluates some of the relationships between stakeholder management and organizational culture from various aspects, each of which requires empirical study to classify and identify the postulated relationships in terms of project success. Furthermore, the paper highlights the benefits of adopting the stakeholder management model in construction projects to achieve project success as well as highlighting the importance of recognizing stakeholder success criteria. The paper goes on to explain the need to understand the types of organizational cultures within construction projects to sustain stakeholders and deliver the project outcome successfully.

The investigation proposed to analyze and empirically-investigate both theoretical models that were presented in the outline research design (as shown in Fig. 3) in the near future in order to derive a wealth of information about the relationship between the two core elements of construction projects in terms of success. From the empirically-derived results, the authors will investigate the findings with the aim of developing a framework that explains the organizational culture and stakeholders' success criteria that determine successful construction projects (see Fig. 4).

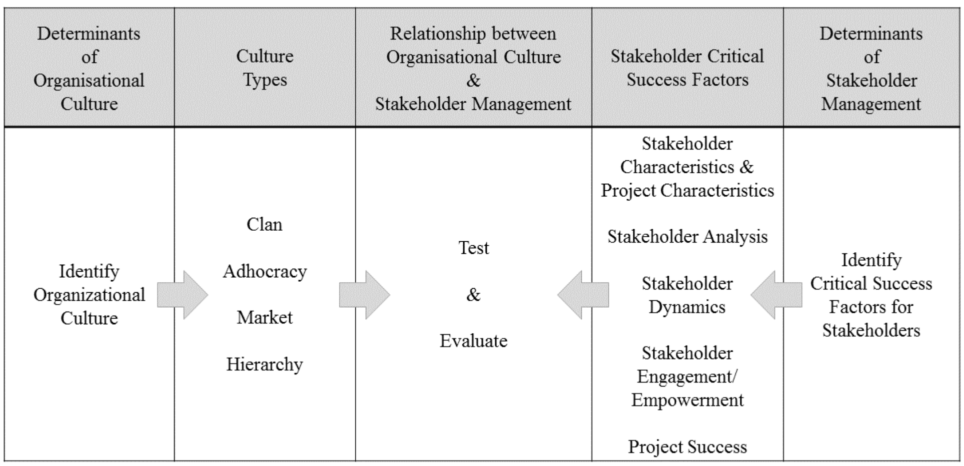

Fig. 4. Schematic conceptual framework

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Perceived Impacts and Solution to Poor Project Management on Abandoned Construction Projects

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Abstract

The menace of missed project objectives such as schedule and cost target overruns with distressing regularity and backlogs of projects waiting to be tackled have largely characterized the construction industry, especially in developing countries like Nigeria. These occur as a result of many unidentified factors (including poor project management) which eventually lead to project failure. This study aims at investigating the perceived impacts of poor project management on abandoned construction projects and the methods that can be used to reduce the impacts. The study employed the survey research design method. The study obtained information from 66 construction profession in Lagos, Nigeria to treat the objectives. The results of the study were analyzed with SPSS software using frequencies, percentages and mean item scores. The results of the study show that, the impacts of poor project management on abandoned construction projects and its stakeholders are conflicts, loss of economic value and reduced standard of living among the citizens. The methods of reducing the identified impacts through project management include adequate planning, use of competent professionals and standard project management procedure. The study concluded that, to reduce project abandonment on construction projects, project managers must incorporate adequate planning, cost control and resource management into their services and engage experienced professionals.

Keywords: Cost overrun; cost control; project failure; project management; project planning

1. Introduction

The impact of poor project management on construction projects across nations including Nigeria cannot be underestimated as it has grave consequences on both the stakeholders (clients, consultants, contractors and users) and nations. The menace of missed project objectives such as schedule and cost target overrun with distressing regularity and backlog of projects waiting to be tackled have largely characterized many developing countries, including the Nigerian construction industry. Poor project performance occurs due to many unidentified factors (including poor project management) which eventually lead to various effects. While project management involves an array of carefully planned, interrelated and organized efforts directed towards the accomplishment of project objectives [1].

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Project abandonment was defined as the decision of management, for whatever reason to temporarily or permanently discontinue a project under development or currently in operation [2]. It was further explained that abandonment is an act of giving up on something completely, with no certain intention of when to resume [3]. Abandoned projects characterize many developing countries, Nigeria inclusive. There are about 4000 abandoned projects which belong to the Federal Government of Nigeria and they were estimated at over N300 billion [4]. The abandoned projects were calculated to take an average of 30 years to complete at the current execution capacity of the government.

Many factors have been traced to abandonment of construction projects. It was discovered in [5] that hostile company culture, political pressure, improper reporting structure, influences, vested interest and inappropriate level of management commitment are the organizational and managerial causes of project abandonment. According to [2], staffing, managerial and communication aspect of project management are the causes of project abandonment. [6] concluded that, although some projects are abandoned as a result of technology or design problems, the main reason behind project abandonment is a lack of understanding of the influence of project management on construction projects thereby leading to project abandonment. Other causes of project abandonment include – lack of social analysis of a project, project imposition, improper financial analysis, under bidding of project and lack of technical analysis [2]. [7] asserted that contractors' bankruptcy, variation of project scope and incompetent project managers are responsible for project abandonment in Nigeria. The factors identified appear endless, but they are mostly connected by project management. That is, many of the causes may be mitigated with proper project management, hence the need to investigate the relationship between project management and abandonment of construction projects.

Abandonment of construction projects as a result of the many factors identified has had devastating effects on both the projects and its stakeholders. [4] declared that project abandonment leads to the disappointment of the populace, low standard of living, wastage of resources, reduction in employment opportunities, decrease in economic activities, decrease in revenue accruing to government, difficulties in attracting foreign loans and increase in final cost of the project. [8] described the impacts of abandoned project as both socio-economic and environmental. [3] opined that, project abandonment has its effect on the individual, community and government.

Since project abandonment has been largely attributed to poor project management [9], it is important to work towards preventing its occurrence by identifying the project management factors responsible for project abandonment, the effects of project abandonment in the construction industry and the strategies that can be used to avoid project abandonment. Against this background, the study investigates the effects of poor project management on construction projects and determine ways of preventing project abandonment that are due to poor project management.

2. Literature Review

2.1. Impacts of poor project management on abandoned building projects

From the background of the study, it could be established that, there are many factors that are responsible for abandonment of construction projects of which, project management related factors are highly rated. Therefore, if the project management related factors could be eliminated, project abandonment could be reduced to a bearable minimum. [10] stated that project abandonments are not always bad, as they can lead to substantial learning and produce artifacts that are applicable to future projects. This was supported by [11] who noted that, project

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abandonment may be a good and acceptable management practice because it may prevent further investment of scarce organization resources in a non-productive venture. On the other hand, however, [10] stated that project abandonment was a corporate resource and is often difficult to deal with because it requires special management skills and critical business decisions.

Various impacts of project abandonment as a result of poor project management have been highlighted in various studies. [12] established that project abandonment has both socio-economic and environmental impacts. Environmental impacts consist of visual impacts, landscape modification, erosion, biodiversity decrease and pollution. Socio-economic impacts consist of increased unemployment, conflicts between public administration and private of population and transfer of cost between private sector, loss of economic value of the area, marginalization of population and transfer of cost between private and public sector.

The effects identified by [4] are: disappointment of the populace, reduced standard of living, wastage/under-utilization of resources, reduction of employment opportunities, decrease in tempo of economic activities, decrease in revenue accruing to government and difficulties in attracting foreign loans among others. [3] noted that the effects of poor project management are felt by the individuals, community and government.

2.2. Methods of Reducing Project Abandonment with Project Management

Many of the authors that worked on the effects of project management on abandonment of construction projects suggested different solution to the problems. This is evident in the works of [11] who suggested that project abandonment can be cured by extending project schedule, better project management procedures, addition of more people to work schedule, increased funding for construction projects, increased pressure on suppliers, reduced scope of project, request for outside help, better development methods, changed technology and performing some other functions.

The solutions suggested by [4] are: adequate planning inception, making funds available, engage competent construction professional, production of economic designs, project scope should not be varied, prompt payment to contractors, partnering, risk appointment, risk review, clear communications, root cause analysis, maintaining morale and right culture, keeping register of uncertainties, reduction of inflation, previously started jobs should not be abandoned for new ideas and strong financial based contractors should be employed. [3] took a multi-dimensional approach by suggesting social analysis, institutional analysis, financial analysis, economic analysis and technical analysis to solve the problem of project abandonment. In addition, [12] suggested that project abandonment can be avoided by conducting users’ satisfaction and needs survey, holding internal technology fairs, ensuring sustained user involvement in product definition, project reviews and studying.

3. Research Method

The survey research design was used for the study. The study was quantitative in nature as it involves the assessment of selected abandoned projects with the use of structured close-ended questionnaire for data collection. Since construction projects fall into different categories such as building, civil and heavy engineering projects, the study focused on building (residential, industrial, institutional and recreational) projects within Lagos, Nigeria. According to [13], any construction related professional such as architect, builder, estate surveyor and valuer, quantity surveyor or engineer would make a good project manager provided there is requisite knowledge, experience of the industry and ability to lead and co-ordinate.

Hence, the population of this study consists of abandoned building projects (public and private) that were executed by construction project managers. The projects used for the study were selected through the non-probabilistic convenience sampling technique based on the ease of collecting data for the study from such projects. The questionnaire for the study was initially administered on ten respondents in order to discover the weaknesses in it. After that, necessary corrections, additions and subtractions were made to the questionnaire as noted by the respondents and validators. Sixty-six out of eighty distributed questionnaires were returned (based on the sampling technique) and analysed for the study. The method of data analysis were frequencies, sums, percentages and mean item scores.

4. Data Analysis

Table 1 shows the general information of respondents and the projects used for this study. On profession, 21.2% of the respondents were architects, 24.2% were builders, 13.6% were quantity surveyors, 25.8% were engineers and 15.2% were into other professions that are related to the built environment like estate management. These professions are the basic fields of study of respondents at the undergraduate level and afterwards, they may go into project management at post graduate and professional level. The table reveals that, architects, builders and engineers are the prominent professionals in the construction project management practice of the Nigerian construction industry.

In addition, 34.8% of respondents have worked for 1-5 years in the project management profession, 42.4% have worked for 6-10 years and 22.7% have worked for 11-15 years. Based on the information, 65.1% of the respondents have between 6 and 15 years of work experience in project management and this shows that the respondents for this study have the requisite experience and knowledge to provide valuable information for this study. Furthermore, 69.7% of the project managers used for this study handled residential projects at one time or the other, 25.8% handled institutional projects and 4.5% handled other types of projects apart from residential and institutional buildings.

None of the respondents claimed to have engaged in religious or recreational projects and this is probably because many religious organizations give the project management aspect of their work to members of their faith (church or mosque) who practice or have idea of the built environment. In addition, there are not many recreation centres in Lagos State, perhaps in Nigeria. Lastly, 25.8% of the respondents' organizations are into sole proprietorship type of business, 13.6% are into partnership, 45.5% are private limited liability companies and 15.1% are public limited liability companies. This indicates that the organizations used for the study are fairly evenly distributed.

Table 1. General information of respondents and their organizations.

Profession	Frequency	Percentage
Architecture	14	21.2
Building	16	24.2
Quantity surveying	9	13.6
Engineering	17	25.8

Others	10	15.2
Total	66	100
Work experience		
1-5	23	34.8
6-10	28	42.4
11-15	15	22.7
Total	66	100
Type of project		
Residential	46	69.7
Institutional	17	25.8
Others	3	4.5
Total	66	100
Gender		
Male	50	75.8
Female	16	24.2
Total	66	100
Respondents organization		
Sole proprietorship	17	25.8
Partnership	9	13.6
Private limited liability	30	45.5
Public limited liability	10	15.1
Total	66	100

Table 2 indicates the impact of poor project management on abandonment of construction projects and construction stakeholders. The impacts with highest rating are wastages/underutilization of construction resources (3.85), conflicts (3.65), loss of economic value (3.62), visual effects (3.52) and marginalization of population (3.50). In addition, reduced standard of living (3.41), pollution (3.39), decreased biodiversity (3.39), erosion (3.29), unemployment (3.29), landscape modification (3.17), disappointment of the populace (3.14) and difficulty in attracting loans (3.02) are impacts of poor project management on projects abandonment with moderate rating.

Table 2. Impact of poor project management on abandonment of building projects.

Effects	Mean	Extent of impact	Rank
Wastage/underutilization of resources	3.85	High extent	1
Conflicts	3.65	High extent	2
Loss of economic value	3.62	High extent	3
Visual effects	3.52	High extent	4
Marginalization of population	3.50	High extent	5
Reduced standard of living	3.41	Average extent	6
Pollution	3.39	Average extent	7
Decreased biodiversity	3.39	Average extent	8
Erosion	3.29	Average extent	9
Unemployment	3.29	Average extent	10
Landscape modification	3.17	Average extent	11
Disappointment of the populace	3.14	Average extent	12
Difficulty in attracting foreign loans	3.02	Average extent	13

5 = Very High Extent (VHE), 4 = High Extent (HE), 3 = Average Extent (AE), 2 = Low Extent (LE), 1 = Very Low Extent (VLE)

Table 3 reveals the methods of reducing the impact of poor project management on abandonment of building projects in Nigeria. Adequate planning at inception (4.58) and engagement of competent construction professionals (4.48) were very highly agreed to by the respondents as methods of reducing project abandonment. Also, standard project management procedure (4.29), clear communications (4.15), good development technique (4.06), increased funding (4.00), employment of strong financial base contractors (3.98), production of economic designs (3.97), economic and financial analysis (3.94), risk apportionment (3.91), change of technology (3.88), risk review (3.82), root cause analysis (3.79), keep register of uncertainties (3.76), ensure sustained user involvement (3.76), conduct user satisfaction and need survey (3.73), maintaining good morale and right culture (3.71), extension of project schedule (3.68), previously started jobs should not be abandoned for new ideas (3.64), government should reduce inflation (3.52) and increasing pressure on suppliers (3.50) were highly agreed to by the respondents as methods of preventing project abandonment in the construction industry.

Table 3. Methods of reducing the impact of poor project management on construction projects.

Solutions	Mean	Level of agreement	Rank
Adequate planning at inception	4.58	Very high agreement	**1**
Engage competent construction professional	4.48	Very high agreement	**2**
Standard project management procedure	4.29	high agreement	**3**
Clear communications	4.15	high agreement	4
Good development technique	4.06	high agreement	5
Increased funding	4.00	high agreement	6
Strong financial base contractors should be employed	3.98	high agreement	7
Production of economic designs	3.97	high agreement	8
Social, institutional, financial, economic and technical analysis	3.94	high agreement	9
Risk apportionment	3.91	high agreement	10
Unvaried project scope	3.91	high agreement	11
Change of technology	3.88	high agreement	12
Risk review	3.82	high agreement	13
Root cause analysis	3.79	high agreement	14
Keep register of uncertainties	3.76	high agreement	15
Ensure sustained user involvement	3.76	high agreement	16
Conduct user satisfaction and need survey	3.73	high agreement	17
Maintain good morale and right culture	3.71	high agreement	18
Extension of project schedule	3.68	high agreement	19
Previously started jobs should not be abandoned because of new ideas	3.64	high agreement	20
Government should reduce inflation	3.52	high agreement	21
Increased pressure on suppliers	3.50	high agreement	22
Partnering	3.36	Average agreement	23
Hold internal technology fairs	3.33	Average agreement	24
Request for external assistance	3.15	Average agreement	25
Addition of more people to the project	3.02	Average agreement	26
Reduced scope of project	2.74	Average agreement	27

5 = Very Highly agreed (VHA), 4 = Highly agreed (HA), 3 = Averagely agreed (AA), 2 = Low agreement (LA), 1 = Very Low agreement (VLA)

5. Conclusion and recommendations of the study

The study investigates the effects of poor project management on abandonment of building projects. The findings of the study are consistent with the work of Carrero *et al.* (2009) in the area of wastage/underutilization of resources, conflicts, loss of economic value, visual impacts and marginalization of population. Other effects such as reduced standard of living, pollution, erosion, unemployment and disappointment of the populace only have average effect on construction project abandonment and were scarce mentioned in previous studies. In this study, adequate planning at inception and engagement of competent construction professionals were rated as the best methods of preventing construction project abandonment. In addition, standard project management procedure, clear communications, good development technique, increased funding, economic designs, risk management, users' satisfaction survey and so on were rated high as solutions to construction project abandonment. However, at the bottom of the list of solutions to construction project abandonment were partnering, holding internal technology fairs, requesting for external assistance, adding more people to projects and reducing scope of projects.

Therefore, based on the findings of this study, it was concluded that, wastages/underutilization of construction resources, conflicts, loss of economic value, visual effects and marginalization of population are the major impacts of poor project management on construction projects. To reduce these impacts, the study further concluded that, adequate planning at inception, engagement of competent construction professionals, standard project management procedure, clear communications, good development technique, increased funding, employment of strong financial base contractors and production of economic designs should be encouraged by stakeholders.

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Practical Application Challenges for Construction Submittals in a Paperless Contract File

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Abstract

This research study explored the transition from a paper to paperless environment for the U.S. Army Corps of Engineers construction submittal process. For several years, the Corps has intended to implement a new multifaceted version of Common Access Card (CAC) enabled Resident Management System (RMS) to include submittal management. The purpose of this study was to provide guidance to make an effective transition from existing paper review process to a paperless digital paradigm, while securely and effectively incorporating multiple requirements and constraints with multiple users. More specifically, how to process digital submittals uniformly and effectively within RMS provided the viability of RMS version 3.0. The implementation of RMS 3.0 would standardize the electronic submittal process, but has had several years of delay. Current policy for electronic submittals is at the discretion of the Contracting Officer. If approved by the Contracting Officer as an option, electronic submittals may be used and referenced in the contract, but no guidance on how the submittals were processed, which promoted inconsistency. This research used PDT (project delivery team) focus groups in order to uncover the challenges and obstacles of using paperless submittals on USACE projects. Recommendations and future research are also addressed in this paper.

Keywords: Submittal, Paperless, RMS, Resident Management System, USACE, Construction, Shop Drawing

Introduction

Construction is a main reason the Corps is in existence. The Corps manages all sorts of projects across the planet, from military construction, public works, and work for other federal, state, local agencies. With over 200 years of existence, and over 35,000 employees, the Corps is entrenched with massive paperwork and bureaucracy. At the bottom depths of construction, at the foundation, the construction industry will find mounds and mounds of paperwork, commonly called submittals.

United States Army Corps of Engineers (USACE) utilizes a program, Resident Management System, affectionately called RMS. RMS assists field engineers, inspectors, construction representatives, contractor staff, and office personnel to perform their duties by providing computer programs and automation to plan, accomplish, and control the daily technical and administrative functions of construction projects managed by the U.S. Army Corps of Engineers. RMS provides a way to plan, schedule, and control all aspects of construction. Resident Management Policy has been provided from Army Contracting Command (ACC). (Project Management Plan for RMS)

Problem is…the Corps is having trouble keeping up with ever changing technology. Within the Federal Government, Department of Defense, Army, and Army Contracting Command (ACC), there have been several directives to go paperless. While the directives, rules, regulations, procedures, bulletins, policy, user guides, guide specifications, and a plethora of other sources are in place; capability, capacity, and security are not. The Corps is actively working the transition from paper to paperless environment for the federal government's construction process. USACE RMS has not kept pace with ACC. RMS has had delays in its initial roll out of version 3.0(almost 4 years). USACE is not going to stop construction because of a broken process. The Corps must persevere and continuously improve RMS.

Background

The U.S. Army Corps of Engineers is a diverse workforce of professionals. Our mission is to provide quality and responsive engineering services for national interest. History and leadership help us meet the demands of changing times. The Corps is a vital part of the Army. The Corps takes pride in our work! The United States Army Corps of Engineers (USACE) is one of the largest public engineering, design, and construction management agencies in the world. Construction management is one of the main missions for USACE. USACE is a federal agency under the Department of Defense (DoD). The Army is a military department within the DoD, and USACE is a major command in the Army. (www.usace.army.mil)

If approved by the Contracting Officer as an option, electronic submittals may be used and referenced in the contract. Submittals transmitted in an electronic format shall meet all current Engineering Regulations, policies, and procedures concerning contractor submittals. The contractor shall provide a plan for effective use of electronic submittals, including ensuring a properly prepared single file structure for electronic submittals. The ProjNet's eSubmittal application (available through www.projnet.org) is USACE's secure, authorized application for electronic submittal transfers, reviews, and storage. The contractor's plan for use of electronic submittals must be reviewed and accepted by the government before start of work, and the plan shall ensure compatibility with the submittal register functionality in RMS. If approved by the Contracting Officer, the contractor may replace all paper submittals, except for color selections, samples, and mock-ups, with electronic submittals. Revisions, updates, or clarifications to the plan shall be made as requested by the government. RMS Quality Assurance / Quality Control (QA/QC) functions are designed to work directly with ProjNet eSubmittal to ensure automated data synchronization. ProjNet eSubmittal reports may also be used to assist in the production of electronic operation and maintenance manuals.

Contractor submittals shall be processed in accordance with ER 415-1-10. Contractors shall manage the work including scheduling, control, certification, and timely submittal of all contract submittals. Submittals shall be transmitted with Attachment B, ENG Form 4025-R, Transmittal of Shop Drawings, Equipment Data, Material Samples, or Manufacturer's Certificates of Compliance, PDF, and PureEdge. (ER 415-1-10)

Purpose of Study/Research Objective

The purpose of this study was to provide guidance to make an effective transition from existing paper review process, to a paperless digital paradigm, while securely and effectively incorporating multiple requirements and constraints with multiple users. More specifically, how to process digital submittals uniformly and effectively within RMS provided the viability of RMS version 3.0.

1. Determine a standard operating procedure and uniform flow chart for digital submittals.
2. What are the potential courses of action for bridging from RMS version 2.38 to version 3.0?
3. Implement a beta test project to help owners, contractors, designers, construction managers, administrators, and software designers make the transition to RMS 3.0.

Rationale for the Study

To help the reader understand and effectively transition from paper to paperless, and moreover, from RMS 2.38 to RMS 3.0.

The transition to a paperless process does not have an adequate infrastructure in place to execute requirements. USACE does not yet have a fully working version of Resource Management System 3.0 in place to receive and store submittals. Army Corps of Engineers Information Technology (ACE-IT) does not have an approved software, secure network, and storage ability in place for the transition. Due to variation of requirements from person to person, office to office, and district to district, an increased probability for error, lost information, and conflict can arise. Can RMS, PD2, and ProjectWise work together?

A transition plan, with a coordinated effort and improved infrastructure, will help make the transition from paper to paperless, and more importantly, a place to receive, comment, document, and store submittals. To transition from RMS 2.38 to RMS 3.0, current policy needs review along with literature, communities of practice, and case studies to determine how challenges impact transition. The Project Delivery Team (PDT) will determine conflicts in policy, shortcomings in system (software, storage, security, etc.) and provide recommendations to overcome challenges in the process.

The PDT will initiate a standard operating procedure, review and beta test courses of action for viability, and provide uniform direction to users and developers to maximize productivity.

Research Design

The PDT was assembled to undertake the challenge of providing a uniform policy for processing submittals. A PDT is the Corps equivalent of a focus group. The PDT included members from design and contract management, with differing levels of experience, including students, interns, engineers, construction managers, and supervisors. The process in the past allowed the Contracting Officer to determine if electronic submittals were to be used, however there was no guidance on how the submittals were processed, which promoted inconsistency. Different software, programs, and various combinations were utilized to transfer and act as a clearinghouse. Those included Email, AMRDEK, ProjectWise, SharePoint – Contractor led, SharePoint – USACE led, and portable storage media, with 2.38 RMS. Each had their pros and cons for performance, but lacked uniformity, which led to increased chance of error.

PDT members introduced a method at our Division's yearly Construction Community of Practice (CoP). This was widely needed since RMS 3.0's rollout had fallen behind schedule by a couple of years. As the PDT worked for continuous improvement, the team produced a Standard Operating Procedure (SOP) and flow chart. The SOP or user's guide with a clear flowchart guidance identified all the different possibilities for submittals, including storage clearinghouse. The SOP was more of a user's manual than anything else, as it included 98 pages. The SOP allowed the flexibility for differing procurement methods with various software and programs. To simplify the SOP to less than 15 pages, the team looked to provide a recommendation for a singular software program.

Research papers, periodicals, and software product literature were reviewed for application for the private sector or other world-wide government agencies. The procedures and benefits of other methods were reviewed. This included lean construction, automated systems, different software, and best management practices. The PDT communicated with other districts pertaining to progression of the submittal process. The team compared, reviewed, and contrasted policy, procedures, and specifications of other districts.

12 PDT users were interviewed to ascertain a static mile-post and sanity check. Results and findings are provided. Findings are a snapshot in time, provided by interviewing each of the PDT members at the time of this paper. The interviews included reviewing, identifying, and recommending bridges to overcome shortcomings, as well as calibrating of the process. Regular team and user group meetings are held to provide instruction to the team and feedback to RMS helpdesk. Our SOP and flow chart are updated regularly.

Five options were analyzed.

1. AMRDEK/Email
2. ProjectWise
3. USACE Led SharePoint
4. Beta Test 3.0
5. Do nothing until 3.0 is rolled out.

Data Collection and Analysis

Data Collection

1. Reviewed current and past regulations, procedures, bulletins, Acts, policy and guidance from multiple references and interpretations. From the Government Paperwork Elimination Act (2000) to the Legal Review of Virtual Contracting Enterprise (VCE), Managed by Paperless Contract File (PCF), as a Repository for Routing, Storage, and Approval of the U.S. Army's Contract File Documents (27October 2015) and many in between.

2. Traced the intellectual progression of the paperless file, as well as, private sector procedures, lean construction, automation, and commercial software packages within research papers, periodicals, and product literature. While the commercial products and procedures researched lead the government sector, practical applicability due to reliability, regulation, and security, slowed the implementation.
3. Evaluated several sources for Federal guidance; Federal Acquisition Regulations, Army Contracting Command PCF Guidance, Engineering Regulations, and Guide Specifications, but it appears the most pertinent, to follow USACE command procedures; ER 415-10 CONTRACTOR SUBMITTAL PROCEDURES, DEPARTMENT OF THE ARMY. U.S. Army Corps of Engineers. 30 April 2012, Enterprise Standard (ES)-08033; Contractor Submittal Requirements, PMB Manual, https://pmbpmanual.lrl.ds.usace.army.mil/Qualtrax/Default.aspx?ID=2539; and Implementing Virtual Contracting Enterprise (VCE) Paperless Contract File (PCF) Initiative, ENGINEERING AND CONSTRUCTION BULLETIN, United States Army Corps of Engineers, 7 Jan 2013.
4. The PDT coauthored a SOP flowchart (see appendix A).
5. Working with others: LRH has been working with other Districts (LRP-Pittsburg District and SWT-Tulsa District) to examine how they are accomplishing electronic submittals. They have provided LRH with specification sections, internal submittal SOPs, checklists, and lessons learned regarding their electronic submittal process. Some of this information will be used on future LRH Contracts, including the Bolivar Abutment Restoration Project.
6. The Huntington District (LRH) has successfully performed similar versions of the electronic submittal process on previous and current projects; Bolivar Seepage Barrier, Bolivar Service Gates, Town of Martin - City Hall/Police Station, and Town of Martin - Alternative School. The Bolivar Abutment Restoration Project will also utilize this current electronic submittal process. Options on one through three had been utilized in the past. The PDT members provided feedback based on empirical data and research, reviewed, and assessed the first three options. Recommendations were provided and presented to supervisors within the Engineering and Construction chain of command for approval and buy -in of proposed procedure. Buy-in allowed for further discussions with Army Corps of Engineers Information Technology (ACE-IT), Division, and ultimately, Headquarters USACE.
7. Where the rubber hits the road, practical application. Implementation of a Beta project of RMS 3.0.
8. Feedback loop to allow for continuous improvement. Regular discussions and meetings to overcome challenges within a dynamic situation.
9. 12 users were interviewed to ascertain a static milepost and sanity check. Results and findings are provided.

Analysis

The three (options) courses of action (COA) were initially analyzed; AMRDEC/email, ProjectWise (PW), and SharePoint (SP).

1. AMRDEC/Email was limited in its use. AMRDEC provides a means for sending large files from a single person to multiple users when email could not handle the attachment size. It required a password, and allowed for extraction for a limited time. Its tracking ability was limited and could not be used as a clearinghouse (central access location). Misplacement of submittals via Email/AMRDEC were problematic. Utilizing previous versions of the electronic submittal process, with the abundance of submittals received/sent via email & AMRDEC, occasionally submittals tend to get lost within daily emails. With this electronic submittal process, the use of the SharePoint/ProjectWise should eliminate lost submittals. SAFE is designed to provide U. S. Army Aviation and Missile Research Development and Engineering Center (AMRDEC) and its customers an alternative way to send files other than email. (https//safe.amrdec.army.mil/safe) It is utilized by other federal agencies for secure transfer of large documents.
2. ProjectWise (PW) was our preferred option. ProjectWise is the standard method for lifecycle document management. (Draft ECB-TBD) PW has add-in modules that contains the tools to perform desired results for document management. (www.bently.com) Once approval and buy-in was obtained from our chain of command, discussions ensued with ACE-IT. From research, outlook was hopeful, but it was anticipated from previous encounters with ACE-IT that implementation may be a challenge. Two major problems arose upon discussion from ACE-IT, time and existing PW version didn't support the cloud add-in required to implement process. Great Lakes and Ohio River Division intends to implement ProjectWise as the project and file collaboration and storage

tool NLT 30 SEP 2018 to enhance regional operations. (OPORD 2016-007) The revised timeline for RMS 3.0 implementation is NLT 31 DEC 2017.

3. SharePoint has preferred functionality of automated notifications of when documents are added/deleted/modified, when things are coming due, and calendar reminders. The Corps of Engineers use SharePoint. Due to security concerns and file size capacity, the team discovered that our use of SharePoint was limited to two types; internal use, by USACE employees only, and contractor led. (www.sharepoint.com)

Interview Questions, Comments, and Findings

Questions

1. How does paperless impact process timeline? Why?
2. How is the paperless system impacting effort to process? Why?
3. Does RMS 3.0 (increase, decrease, the same) increase the chance for error? Why?
4. What options are you implementing when uploading submittals in RMS 3.0 fails?
    a. Email
    b. AMRDEK
    c. SharePoint
    d. ProjectWise
    e. other.
5. What are you doing when to promote paperless or the operability of RMS 3.0?
    a. Using 2.38 and 3.0 simultaneously
    b. Beta testing
    c. User group training
    d. Nothing, waiting on 3.0 to work correctly
    e. Call problems to helpdesk
    f. Playing with the program
    g. SharePoint
    h. Other
6. How many submittals do you review in week?
7. How much time do you spend on submittals?
8. Position?
9. Do you have RMS 3.0?

Results provided in Appendix 1.

Comments

The Good

1. Saves the Government time and money.
2. Less unnecessary handling.
3. Tracking. Very little time to generate a report.
4. Easier to find submittal in the process, or for instant availability in the field to see requirement.
5. Beta test experience: LRH has successfully performed similar versions of the electronic submittal process on previous and current projects; Bolivar Seepage Barrier, Bolivar Service Gates, Town of Martin - City Hall/Police Station, and Town of Martin - Alternative School. The Bolivar Abutment Restoration Project will utilize RMS 3.0.
6. Collaborating with other districts: LRH has been working with other Districts; LRP – Pittsburg District and SWT-Tulsa District to examine how they are accomplishing electronic submittals. LRP and SWT have provided LRH with specification sections, internal submittal SOPs, checklists, and lessons learned regarding their Electronic Submittal Process. Some of this information will be used on future LRH Contracts, including the Bolivar Abutment Restoration Project.
7. Less paper: The reduction of unneeded paper copies of submittals. This process only requires Contractors to provide the Government two (2) hard copies of submittals for our Contract File Copy & the Inspector Copy. In the past, USACE have required the Contactor to provide six (6) hard copies of all submittals. All Electronic Submittals are stored and received/sent digitally. Providing a savings on postage and paper, for the Government and our Contractors.

8. The Electronic Submittal Process is much faster: USACE do not have to wait on postal services to obtain and return submittal back and forth with the Contractor and Submittal Reviewers. Submittal Reviewers can begin submittal review the day it received from the Contractor and Contractors can obtain the completed submittal the day of approval.
9. Comments into RMS: Engineering provides submittal review comments directly into RMS.
10. Electronic submittals can be accessed anywhere: Within the District Office, in the field, on mobile phones, and tablets, without having to locate the hard copies in filing cabinets or transport hard copies to the field.
11. Reduces error. Misplacement of submittals via paper, Email/AMRDEC: Utilizing previous versions of the electronic submittal process, with the abundance of submittals received/sent via email & AMRDEC, occasionally submittals tend to get lost within our daily emails. The use of RMS 3.0 with ProjectWise should eliminate lost submittals.

The Ugly

1. Tracking of submittals that are "in review": This current process is not an efficient means to track where a submittal is currently in review with the Resident Engineer, with the Lead Engineer, with the Technical Engineer. This Process requires personnel that handle a submittal at any point to manually enter tracking dates and recipient names into the RMS Submittal Comments block, so that anyone that needs to know where a submittal is in review can access this information. A technician will be assigned this duty in the future. A standard operating description is in the works, with applicable position description.
2. Misplacing final submittals within ProjectWise: Construction Submittal Coordinators do a great job at placing the final submittal into ProjectWise. Occasionally this does not occur. This process has included several "checks" to ensure that process error is minimized, but human error can still transpire.
3. Field Connections: ProjectWise and RMS are running via network connections; this process will be frustrating to field personnel when connectivity is limited.

Areas of Improvement

1. Permanent storage of electronic submittals: Currently LRH is storing electronic submittals within the RMS "Contract File", on ProjectWise, on the local networks, and now on SharePoint. Some of these storage locations are redundancies, but some are required. It is unknown to LRH if the RMS "Contract File/Paperless Contract File (PCF)" storage can be accessed once a Contract is "Archived" in RMS. Is RMS/ a good a long-term storage location? LRH needs to further investigate permanent storage possibilities to eliminate these redundancies. (OPORD 2016-007)
2. "How-To" Presentation: Providing an Electronic Submittal Process Presentation to all of Engineering and Construction personnel that handle/review Submittals. Giving systematic instructions on this process, answering questions, and providing explanations on why some of these steps the way they are.
3. Continually improve the "Living" Flowchart and SOP (PowerPoint): The Flowchart and SOP (PowerPoint), are "living" documents and most likely will need to revise/change as programs and situations change. However, the PDT would like to "finalize" these so that a new person to the District or new to this process can take these two documents and fully complete their portion of a submittal without help.

Findings

The findings for this topic were provided by a focus group, or as it is called in the Corps, a PDT. The PDT provided initial recommendations to management, and was subsequently approved. Findings are a snapshot in time, provided by interviewing of each of the PDT members at the time of this paper. Calibration of our process includes reviewing, identifying, and recommending bridges to overcome shortcomings. Regular team and user group meetings are held to provide instruction to the team and feedback to RMS helpdesk. Our SOP and flow chart are updated regularly.

Beta testing of RMS 3.0 is occurring on the Bolivar Abutment Restoration Project. Implementation of 3.0 was a contractual obligation for the contractor and the Government. Neither had fully implemented 3.0 at the time of award. Once the contractor implemented 3.0 there was no going back to using 2.38. It was published (https://lrh.intranet.army.mil) to district leads that the newer contractor 3.0 version was ready for roll out, but USACE side was still under construction and had some bugs to work out. USACE administrators have been given the ability to process submittals in 2.38 and 3.0. The Contractor had not even started the implementation process. The process needed to be flexible once shortcomings were discovered.

Two interesting things happened prior to the contractor upgrading his version of RMS 2.38 to RMS 3.0; district headquarters prematurely required closing the field office by 31 DEC 2017 and a modification to the contract, the abutment had a soil slip.

To keep this project tracking to meet a challenging schedule, and to expedite Notice to Proceed (NTP), the contractor was required to email his initial submittals, while initiating RMS 3.0. High priority was given to the review of the initial submittals. The submittals were temporarily processed in USACE share drive and stored in PW. Since implementing RMS 3.0, the contractor continues to have learning curve problems. A user manual has been developed to assist the contractor to utilize RMS 3.0. The project engineer (contract management) and lead engineer (civil design) have led the implementation of RMS 3.0 with the contractor and field personnel, while reviewing, identifying, and recommending bridges to overcome shortcomings. Regular team and user group meetings are held to provide instruction to the team and feedback to RMS helpdesk. Our SOP and flow chart are updated regularly. The Project Engineer (PE) has had to provide additional assistance to the Contractor for this implementation.

The PE has provided the Contractor:

1. A SOP on how to process a submittal.
2. PE has contacted help desk for feedback and patch support.
3. Directions to resolve shortcomings, with follow-up work to keep contract file up to date.
4. RMS 3.0 Power Point Workshop for general Contractor use.

Implementation for Beta project is initially cumbersome, requiring extensive communication, follow-up, and re-work. RMS 2.38 and RMS 3.0 need to be open in two separate screens to process submittals. Direct storage of submittal in RMS is helpful to quickly access files and reports. Construction season is a challenging time for Beta testing.

Every interviewee concluded that paperless will save the government money, improve the project timeline, and require less effort to process. 92% believe RMS once fully implemented will reduce the chance for error. Like every new or modified software package, there is a learning curve associated with its implementation. The learning curve is challenging when dealing with small businesses that have limited personnel.

The PDT was genuinely excited with the concept of two computer programs to process submittals. The less email, programs, or software to process submittals, and the more streamlined “one stop shop” is provided, the better the process. With RMS 3.0 to be completely implemented by year’s end, the Corps of Engineers has finally caught up with the information age. USACE has provided direction in Operational Orders combination of RMS and PW will be the two main programs that Engineering and Construction will use. Construction is married to RMS and with the unknowns of RMS 3.0 capabilities, the PDT can take advantage of reducing from three (3) software programs to two (2) software programs.

Great excitement ensued with the PDT, as it was discovered that ProjectWise, the project and file collaboration and storage tool, contained elements for real time information tracking. The problem is that the latest version is still in ACE-IT getting approved. From our research, PW Deliverables has real-time tracking and helps with accountability. Pre-sets keep process moving with notifications and a Dashboard. The PW software is extremely user friendly and familiar, as USACE is currently all working in PW. The PW automation is much like the SharePoint automation, but adds the automated feature of archiving, as well while ensuring packages are intact. “Packages” is what PW calls a submittal package. Packages are created by contractor and sent via cloud. Like sending zip files, PW will set files to keep content intact, large, and small. The difference is, it is set up and maintained automatically throughout the process. Archiving is a huge portion of the current process, which is flawed with naming conventions not matching, and lost files which can all be fixed automatically with this add-in cloud. A RFI process is built in to this add-in. It appears that PW will help streamline the current RFI process.

Conclusions and Future Research

From the results of this study, USACE can conclude that transitioning to RMS 3.0 and going from paper to paperless will be a cost, time, and effort savings once implementation can occur. Continued bridging efforts by the PDT and staff will continue.

Conclusions

1. Saves the Government time and money.
2. Less unnecessary handling.

3. Quicker and Easier Tracking. Very little time to generate a report.
4. Easier to find submittal in the process, or for instant availability in the field to see requirement.
5. Successful beta testing experience.
6. Collaboration promotes effectiveness and economy of scale.
7. Less paper.
8. The electronic submittal process is much faster.
9. Engineering provides submittal review comments directly into RMS.
10. Electronic submittals can be accessed anywhere.
11. Reduces error.

Future Transition

1. The use of paper, scanning, email, AMRDEC, and other uses of transferrable devices.
2. Implementation of a fully functional RMS 3.0.
3. Contractor Training.
4. USACE Training. "Train the Trainer"
5. Revised master specifications for submittals.
6. Revised roles and responsibilities to accommodate the change in basic assumptions from paper to paperless.
7. Improved hardware and software.
8. Process security.

Future Research

1. Permanent Storage of electronic submittals:
2. "How-To" presentations.
3. Finalize the "Living" flowchart and SOP (PowerPoint).
4. A contractor's RMS 3.0 user manual, SOP, or power point to assist in productivity, which will promote "partnering" and good will.
5. A technician will be assigned as submittal technician in the future. A personnel description is in the works.

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Product service systems in construction supply chains

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Abstract

The shipbuilding, automotive and aerospace industries are examples of industries offering product service systems (PSS) to their customers, i.e. they combine physical products with services to add increased value. While product service systems are well established in many manufacturing industries, it has barley emerged in construction, which is mainly explained by the well-established project-based organisation of construction work. Thus, implementation of product and service systems in construction will challenge the established utilisation of technical solutions and systems, production processes and supply chains. The objective of this study is to identify and critically review examples of product service systems in construction supply chains, with the purpose of describing how it challenges prevailing business systems and organisation of construction work. The study rests upon empirical data collected in two case studies at Gyproc Saint-Gobain in Denmark and Celsa Steel Service in Sweden. The two case studies reveal significant challenges related to the implementation and marketing processes of product service systems. Companies that develop and expand their business offers by providing new product service systems find themselves operating in two parallel market segments, i.e. the traditional market of construction components and the new market of product service systems. The product service systems reviewed in the two case studies show a strong focus and emphasis on the development of the offer and the operational platform, while the companies' roles and market positions remain unchanged. Thus, the case study companies organise and operate their businesses and market relations as before the implementation of the product service system. The conclusion is that development and implementation of product service systems in construction supply chains, even at the low end of product complexity represented by single building components, require awareness in the companies' offer of products and services, development in operational platforms as well as clear market position.

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Keywords: Product service system; Operational platform; Market position; Industrialised construction

1. Introduction

A product is the result of a repetitive process that utilises a pre-developed structure of solutions for design and production [1]. The product approach is fundamentally different to the traditional project-based construction, where buildings are produced as uniquely designed, one-of-a-kind solutions, executed by temporary teams in loosely coupled supply chains [2,3]. A product-oriented company specialises in offering a specific range of products that allows for repetitions and continuous improvements over time, in order to establish an efficient manufacturing process and supply chain. Production methods, technical solutions and sub-systems can be predefined and enable efficient end-product configuration, due to the limitations of the scope of the product [4].

Product platforms constitute systematic structures of subsystems used for development and production of derivative products [1]. Robertson and Ulrich [5] describe product platforms by four distinctive aspects, namely components, processes, knowledge, people and relationships. Production platforms are optimised for efficient delivery by executing design, production and supply of materials in cooperative and recurring processes by integrated teams engaged on a long-term basis. Further, product and platform development require a clear perception of the customer's needs, requirements and priorities in order to tailor attractive and competitive concepts [4] aimed at certain market segments [1]. The specific importance of including the customer focus in a product-oriented production system is also emphasised by Barlow and Ozaki [6], Barlow et.al. [7] as well as Lessing [8]. These authors conclude that product-orientation requires long-term investments in platform development, production facilities and accordingly, a clear understanding of the customers' needs is crucial for the design and development of product concepts.

Production-orientation implies control and predictability of the planning, design and, production processes, which allows for improved quality and customer value of the produced goods. Besides, product-orientation facilitates additional opportunities in a long-term perspective. Other industries such as the shipbuilding, automotive and aerospace industries show an increased focus on combining physical products with services [9]. Accordingly, the combination of products and services could provide similar opportunities for e.g. manufacturers of building materials and industrialised construction companies in order to expand their offerings.

A product is composed of a physical part, i.e. the tangible product that is manufactured and offered to the customers, and of an intangible part that consists of the various services that are offered to the customers [10]. Offerings that systematically combine both tangible and intangible products, i.e. products and services, are commonly referred to as product service systems (PSS). The concept of PSS has been defined by several authors, e.g. [11,12,13], only with minor variations in their definitions. The common understanding of PSS is that it represents a systematic way of structuring a combination of tangible products, services and the networks needed to satisfy customer needs. Manzini and Vezzoli [12], defines a product service system as a combination of physical products and services that affects the company's offerings and business scope:

"A Product Service System is an innovation strategy, shifting the business focus from designing (and selling) physical products only, to designing (and selling) a system of products and services which are jointly capable of fulfilling specific client needs".

1.1. Problem statement

While product service systems are well established in many manufacturing industries, it has barley emerged in the construction industry. Construction is characterised as an industry producing complex one-of-a-kind projects, in temporary organisations using mainly onsite production methods [2,3]. Supply chain integration is scarce due to a fragmented process dominated by short-term relations [13]. Temporary design teams from different consulting firms carry out the design and a variety of contractors use project-specific production methods on site [14]. The traditional organisation of construction work offers limited incentives and possibilities to establish systematically repeated and improved methods, design solutions and processes in a long-term perspective [15].

The implementation of product service systems in construction can however, provide new business opportunities by combining physical products (e.g. building materials, components, prefabricated elements, building blocks etc.) with intangible services. The knowledge and experiences of product service systems in construction is still limited, as there is only a limited amount of research done in the field. Some researchers, however, touch upon the topic. For example, Brady et.al. [16] explore the opportunities and obstacles for applying integrated solutions in the construction industry, which are described as combinations of products and services that address customers' requirements, and thus are conceptually similar to PSS.

Brady et.al. [16] state that companies need to structure its business around repeatability in terms of both technical systems and services offered, as well as standardised processes, in order to implement integrated solutions. Further, they conclude that a PSS-approach requires maturity in the PSS-offering, investments in operational capabilities and a surrounding market that is open for the PSS-offering. Besides, Lessing [8] mentions PSS as an opportunity for industrialised construction companies to develop their offering and create new business models and revenue streams.

1.2. Purpose and objectives

The objective of this study is to identify and critically review examples of product service systems in construction supply chains, with the purpose of describing how it challenges prevailing business systems and organisation of construction work.

2. Method

The study rests upon a literature study and empirical data collected in two case studies of which one was carried out together with Celsa Steel Service in Sweden [17] (referred to as Celsa in this context) and the other one was done in collaboration with Gyproc Saint-Gobain in Denmark [18] (referred to as Gyproc). The case studies were carried out in order to identify and critically review examples of product service systems in the two companies.

The collection of empirical data was primarily done by semi-structured interviews, which was supplemented by company and product documentation. Altogether, eight interviews were carried out with key-representatives from the two companies of the case studies. All interviews were recorded, transcribed and returned to the respective respondents as a quality check.

3. Product service systems in construction

Research on business models for house building and construction companies is scarce [19], but emerging. Brege et.al. [20] were some of the first to present an evaluation of business models in the construction context of industrialised building. Other resent research contributions on business models in this field have been presented by e.g. Höök et.al. [21] and Lessing and Brege [22]. Brege et.al. [20] made a central contribution in terms of a business model framework based on three cornerstones required for describing a house-building company's business model, namely the operational platform, the market position and the offering, see Fig. 1.

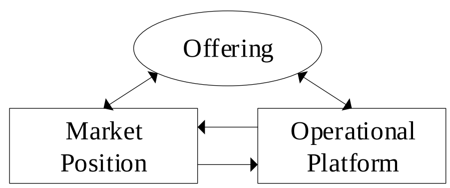

Fig. 1. The business model framework used as the basis of analysis in this study [20].

The business model framework provides the basis of analysis for the two case studies in this context. The offering in this case, represents the PSS-value proposition, i.e. the product and the service provided by the respective companies. The operational platform describes the company's resources and competences, e.g. production facilities, supply systems, information infrastructures, R&D-support etc. The market position describes the company's role in the market place and supply chain.

3.1. Case 1: Celsa Steel Service – prefabricated reinforcement cages

Celsa [17], one of seven companies of the Celsa Group [23] is a leading European manufacturer of a wide range of reinforcement solutions such as detailing, carpet reinforcement, prefabricated welded products, pile cages, just-in-time delivery and client management systems.

3.1.1. The PSS-offering

The PSS-offering described in the Celsa case study includes prefabricated reinforcement cages, e.g. for foundations, pier footings, beams, pillars etc. and the additional services includes structural reinforcement design in 3D, quantity take-offs, industrial (i.e. automated) prefabrication and colour coding and other logistical services. Celsa's main arguments for the PSS-offering are improved health and safety, time and cost savings, quality improvements etc. for the contractor, which are accomplished when moving the hazardous and tedious reinforcement work from the construction site to prefabrication in an industrial and automated production facility.

3.1.2. Operational platform

The operational platform of Celsa consists of a highly automated industrial facility producing all the various prefabricated reinforcement products, e.g. the reinforcements cages highlighted in this case study. The service part of the operational platform supports the production line and provides services in terms of 3D-design, quality control and clash detection, logistical services and an information management system.

3.1.3. Market position

The company has two lines of businesses. The first and original one is the production of raw standard reinforcement products such as bars, coils and wire rods sold by tonnage. The other line of business represents the refined prefabricated reinforcement products and additional services as described in the PSS-offering in this study. The development of PSS-offerings and its added value to their customers is a way for Celsa to answer to the increasing competition from international suppliers of raw, unrefined, reinforcement products.

3.1.4. Review of Celsa's PSS-offering

The PSS-offer of Celsa represents a resource-based, i.e. an inside out [24], business approach based on the company's technological knowledge and competences, production facilities, information and logistical infrastructure and other resources. An essential requirement for this approach is the ability to exploit the internal and external competences, but also to find a market demand and to create value for their customers [25,26].

However, Celsa has not yet fully managed to create this market demand for their PSS-offer. Contractors principally ask for raw reinforcement products for single building or construction projects and select their reinforcement suppliers by lowest price per tonnage. Accordingly, Celsa still competes with other suppliers by lowest prices on raw reinforcement products, and their PSS-offering is reduced to a potential after-sale if they win the original bid.

Thus, this is an example of where the market position and business models are not renewed in parallel with the development and implementation of the PSS-offering. Instead, Celsa still operates in the traditional market place of raw reinforcement products, and consequently, face difficulties to promote and market their PSS-offering.

3.2. Case 2: Gyproc – The XRoc wallboard system

The Gyproc case reviews the product and services related to the new XRoc wallboard system, initially introduced in a hospital building project in Denmark called "Det Nye Rigshospital" (in Danish) [27].

3.2.1. The PSS-offering

This PSS-offering is represented by Gyproc's new wallboard system called XRoc and its related services in terms of technical design, assembly instruction and performance validation. The XRoc wallboard is specially designed to absorb ionising radiation (e.g. X-Rays) from CT scanners and similar devices frequently used in hospitals. The XRoc wall system is free from lead, which significantly improves the health and safety aspects compared to the handling and erection of traditional lead-based wallboards.

3.2.2. Operational platform

Gyproc is an international company with 12 000 employees in 56 countries with a long experience in developing, manufacturing and distribution of lightweight gypsum plasterboard systems for interior walls and ceilings and other building materials [28]. Gyproc's operational platform is competitive, well developed and is supported by the global Saint-Gobain Group [29], of which Gyproc is one of about 1 000 companies. The XRoc wallboard system is a result of internal research and development carried within the Saint-Gobain Group.

3.2.3. Market position

Gyproc's business partner in the hospital project of this case study is a wholesaler of building materials, from which the contractor orders the XRoc system, traditional gypsum boards and other goods provided by Gyproc. Thus, Gyproc has a remote market position, with no direct business relations to the contractor or other actors of the building project.

3.2.4. Review of Gyproc's PSS-offering

Gyproc's PSS-offer represents a market–based, i.e. an outside-in, business approach where the contractor's demands and needs provide the starting point [30]. During the project the contractor turned to Gyproc asking for help and support with the design and validation of technical solutions for e.g. ventilation ducts, electrical switches, walls plugs, door cases other connections through the XRoc wallboard system. Traditional led-based solutions were not allowed in the project due to client demands.

It is perfectly in line with Gyproc's general business idea to develop and market technical solutions for their customers. However, Gyproc's market position in the hospital project did not support this strategy. As Gyproc had no business relation with the contractor of the building project, there were questions and uncertainties about the liabilities and warranties of the technical solutions provided and not least, the reimbursement for Gyproc's services. Obviously, Gyproc needs to establish a market position higher up in the value chain in order to support the PSS-offering of the XRoc wallboard system.

4. Conclusion

The two case studies reveal significant challenges related to the implementation and marketing processes of product service systems. The companies that are developing and expanding their business offers by providing new product service systems find themselves operating in two parallel market segments, i.e. the traditional market of construction components and the new market of product service systems. The product service systems reviewed in the two case studies show a strong focus and emphasis on the development of the offer and the operational platform, while the companies role and market position remains unchanged. Thus, the case study companies organise and operate their businesses and market relations as before the implementation of the product service system. The conclusion is that development and implementation of product service systems in construction, even at the low end of product complexity represented by single building components, require awareness in the companies' offer of products and services, development in operational platforms as well as clear market position.

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Proposal for typology and definitions of service categories in a general PMO model

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Abstract

The strategic importance of project management offices (PMOs) is not questionable therefore identifying the most specific and noticeable evaluation segments of PMOs leads to a better understanding of PMOs. As a starting point in our earlier publication along with the quest for the determination of a standardized, integrated, and comprehensive framework, we defined a PMO model summarizing grounding ideas of our research. This complex PMO model contains six building blocks that describe the complex role and status of PMO within the organization: the context (the environment of the PMO), the typology, the maturity, the internal processes of the PMO, the services, and the performance (the metrics of the PMO).
This study concentrates on the services and the typology of a PMO, based on a deep dive in the different approaches of these two categories. We achieve this first by elaborating a clear description of them and secondly by analyzing the relationship between them and the other categories of the model.
In our model, among the six categories 'typology' has the most direct connection to the organizational structure that a PMO serves. Following the analysis of state-of-the art and relevant publications about this category, we recognized that the typology has various definitions leading to diffuse meaning. This research clarifies this concept to give a proposal for the exact definition of typology.
Publications on PMO 'services' do not emphasize the definition itself enough. Instead, they focus on the PMO responsibilities within an organization, the needs, and the objectives to achieve. Our research provides a collection of all the service elements, and different grouping concepts of them. In his study we suggest a unified list of PMO services, their descriptions, and a grouping approach in line with the aim of PMO operation.

Keywords: Project management office; evaluation framework; maturity; services

1. Introduction

The purpose of this research is to provide a developed, integrated new framework for PMOs, which measures the processes more accurately. In order to achieve this goal, we need to define a model; it is difficult because PMOs have a double nature. On the one hand, they have to be considered a stable, unchanged organization, but on the other hand, they have to be examined as constantly changing organizations, too. Our model grants an opportunity to benchmark PMOs of other companies.

We build our proposed model on an extensive literature review rather than the usual questionnaire-based solutions, and perform the analysis and processing using a mixed, qualitative and quantitative method. In the quantitative part of the research, we analyze the articles as survey elements quantitatively (count them), and build and interpret the model like this. In addition, a qualitative approach should also be used for the sake of completeness (e.g. What are the roles within a PMO? How do we structure them?). In establishing the model, different, already published PMO approaches,

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models and their structure and building blocks have to be interpreted. In our work, we unified the information from the very diverse literature background.

Monteiro, Santos & Varajão (2016) listed many different terms around the PMO, based on the database search in their research: i.e., type, model, typology, typologies, framework, functions, roles, organizational project management, project management maturity, and project governance [1]. This one is a demonstrative and persuasive example for cleansing the terminology that we are researching, analyzing, and proposing in our work. Based on our extensive literature overview referring to our earlier described model [2], we set a terminology catalog on the PMO (Table 1).

Table 1. Terminology catalog for the Model/System.

Model/System						
Structural elements Building elements Components	Types	Services	Own Processes	Context	Maturity	Performance
Relations Connections Links	Categories Natures Configurations	Services Functions Capabilities Features Roles	Internal processes Operation	Environment Governance rules Project culture	Properties	Indicators
	attributes					

2. Typology

In different dictionaries the definition of "typology" on one the hand is a classification of elements according to their characteristics, structural features, and specialties, describing the distinctions between them, and on the other hand it is the branch of knowledge that deals with classes with **common characteristics**. According to Mintzberg, typologies are useful when dealing with complex phenomena, and the study of organizations. He concluded that organizations could be grouped into five internally consistent and **clearly differentiated** configurations [3].

Table 2. Merging terms.

Terms are merged	**To**	**Comment from the original publication**
Business Project Office	Business Unit PMO	
Functional PMO	Business Unit PMO	
Headquarter PMO	Enterprise PMO	
Business PMO	Global PMO	Delocalization strategy
Federated PMO	Global PMO	
Project Repository	Knowledge PMO	
Technical PMO	New Product Development PMO	Focused on technology that is changing rapidly
Supporter	Project Support Office	

In our case, the type of PMO is a central component, but it is still only one of the 6 building components of our model, therefore the typology definition should follow the characteristics described above, and should not incorporate the attributes from other structural elements (i.e., services – authors use the major classification of services offered by the PMO).

We have collected and summarized several „typologies" of the PMO found in the literature. Monteiro, Santos & Varajão [1] gave a good basis for our typology list. We checked their assessments reviewing the referred publications and modified the classification if we noticed discrepancy.

Based on the typology assessment of 20 publications, 38 kinds of PMO are named with 95 instances of mentioning. Details can be found in Appendix A. While studying the results, we recognized similar wordings and terms. We made the merges in Table 2 with the following rules:

- Categories of two rows cannot be merged if within a given publication two categories were differentiated even they can be candidates for merging based on the approaches in other publications.
- Real interpretation of the content of terms should be cross-checked in the original source before the merge.

An important and interesting term is 'validation'. In the description of the Project Management Strategic Integration Office (PMSIO), we can find the "translation of the business/strategy demands", which means that this PMO type provides an advanced kind of a recent trend, business analyst support. Therefore, built on this interpretation, we renamed PMSIO to Business Analyst Services. After reworking the sheet in Appendix A based on these modifications and taking into account the occurrences, we got the top mentioned types of PMO. (Table 3)

Table 3. Top mentioned types of PMO.

Types	Occurrence	Before 2010	After 2010
Enterprise PMO	13	6	7
Program Management Office	9	5	4
Project Support Office	9	5	4
Business Unit PMO	8	**2**	**6**
Center of Excellence	8	5	3
IT PMO	5	**1**	**4**
Project Office	5	2	3

Monteiro, Santos & Varajão (2016) and Hobbs et al. (2010) raise the phenomenon of 'changing in time' of the preferred or operated PMO models [1], [4]. To test this hypothesis, we split all the occurrences of the most established PMO types into two categories: before and after the year 2010. The timing dimension did not give a really new classification point, only the occurrences of the Business Unit and the IT (Information Technology) PMOs show significant differences. (Table 3) In our general model typology point of view we are considering IT as a business unit.

While reviewing the remaining "types" of PMO in the list, in the literature we recognized that they were differentiated on a diverse basis: many times, the service or other components of our model was the differentiating factor, the "differentia specifica".

In Table 4 we summarized these "non-types" according to the elements of our model. On the other hand, these attributes are proper and valid inputs for analyzing and building up these model elements.

Table 4. Non-types elements.

Services	Own Processes	Context	Maturity
Consulting PMO	Knowledge PMO	Global PMO	Basic PMO
Information Manager	Controller	Country PMO	Standards PMO
Project Coaching	Delivery Service	Regional PMO	Advanced PMO
Business Analysts			Mature PMO
Change Operations			
Coordinator			
Planning			
Portfolio Management			

The classification in Table 4 is easy to follow, understand and accept, only the Context column needs some further explanation. While the top ranked types refer to the organizational role of the PMO, the attributes listed in the Context column show a geographical approach. If the organizational and geographical differentiation appear parallel, it is better to use the organizational distinction because from our point of view the PMO should be considered as an organizational

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entity rather than a geographical one. If they are different, the geographical impact can be calculated as a contextual element of the PMO.

After this cleansing, some types with a low number of mentions remain. We consider these as part of the typology (as they cannot be included in the other elements of the model); however, because of our strict merging rules we cannot consider them as major types.

Following the merge, the New Product Development PMO has 2 occurrences, while the Customer Group PMO and the Division PMO both have 1 occurrence.

Reviewing the description of these PMO types in the original publications, we can see that

- New Product Development PMO is a real Business Unit PMO.
- Division PMO can incorporate more than one Business Units.
- Customer Group PMO is a Business Unit PMO with a specialty providing not only internal services.

Our conclusion concerning these items is that on the one hand at our level of abstraction in our typology they belong to the Business Unit PMO line, and on the other hand they indicate the difficulties of modeling because of the diversities of PMO in types and services. In our research we reached the following list of potential types of our typology:

- Enterprise PMO
- Program Management Office
- Project Support Office
- Business Unit PMO
- Center of Excellence
- IT PMO
- Project Office

Thinking the list above further, we concluded on the following typology.

1. **Dedicated PMO:** project or program PMOs operate as temporary entities in an organization – because of its more general naming, we can use this category for typifying the special type PMOs;
2. **Business Unit (BU) PMO:** responsible for providing service for a specific unit of an organization (including divisions, departments) especially IT (as BU). Frequently this is the ordinary PMO.
3. **Enterprise PMO**: responsible for the alignment of projects/programs with corporate strategy (sometimes it is also called Strategic or Global PMO)
4. **Project Support Office**: provides enabling processes for the organization;
5. **Center of Excellence**: provides tools, standards and methodology for project managers (sometimes also referred to as Center of Competency).

The defined PMO types can provide different services based on their own specific operation and process, they can be on different maturity level and their performance evaluation can be based on their independent mission. They are definitely impacted by their organizational environment.

3. Services

As we have highlighted in our typology section, the services a PMO is providing is very much dependent on the type of PMO we consider: the services provided are dependent on its responsibilities within an organization, the objectives of the office as well as the means needed to reach them. The services provided have to be maximally aligned with the strategy and needs of the organization they are supporting. Literature reviews in this area make a considerable effort analyzing one or more service groups a PMO is providing; as already stated, our goal in this paper is to consolidate them.

3.1. Definition of Services

Artto et al. (2011) have pointed out that a PMO is typically considered a specialized formal organizational unit that is responsible for some specific task(s) [5]. Therefore, a PMO is considered a specialized unit being just one in a group of many mechanisms for integration. It is an integrative structure and organizations do not necessarily have a PMO but they have arrangements that provide these services. Therefore, even if a formal PMO does not exist, the services provided are required in all project driven organizations. The responsibilities of the PMO can range from providing project management support functions to actually being responsible for the direct management of a project [6]. When discussing the basic roles of a PMO, Müller et al. (2013) have identified the services as one of the 3 elements besides control and partnership [7].

3.2. Elements of Services

In the literature that we have reviewed, the authors have identified several services and service groupings that a PMO can provide. We have listed these services and assigned them into groups. We have followed the following rules while assigning them to groups:

- One service can only be part of one group.
- The content of the service group is the main driver.

Based on this activity, we have identified 5 Groups. After re-assessing our grouping, we propose the following 4 groups of Services that a PMO can provide (Appendix B):

- Operation support services (Group 1 + 2). In this group we consider all activities that are related to the support of the PM activities of an organization: standards, processes, methodologies, administrative support, and reporting.
- Monitoring and controlling services (Group 3). All financial activities related to a project are in this group: controlling activities, financial monitoring, profitability and productivity checks, and budgeting.
- Human resource management services (Group 4). The services in this group are all related to the human capital of the organization: training, talent management, benefit management, HR consulting services and knowledge management.
- Strategic and portfolio management services (Group 5). This group contains all activities linked with the alignment of the PMO to the strategy of the organization it is supporting: evaluation and selection of projects, program management, portfolio management, communication management and quality management. This service group has a high dependency on maturity (one element of our model): the more mature the PMO is, the more services from this group are provided.

4. Conclusion

In one of our earlier papers, the starting point of our research was a definite standardized, integrated, and comprehensive PMO framework. Building on the model containing six building blocks, this paper focuses on the categories typology and services, processing the wide range of literature sources quantitatively and qualitatively.

Our plan is to continue the bottom-up analysis of the building elements and create a well-established definition of the attributes of the elements based on a wide literature analysis and practical approach including incorporating knowledge from portfolio management software applications and algorithms.

One of our important observations during analyzing the typology and services is the dependencies and relational connections among the elements of our model. We are going to research this relation aspect deeply after detailed definition is finished.

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Appendix A.

Source of analysis	4	1	1	2	1	2	3	2	2	3	1	3	3	1	2	3	2	3	2	3			
1 - Assessment by Monteiro, Santos & Varajão (2016) 2 - Assessment by Monteiro, Santos & Varajão (2016) with the authors' review 3 - Authors' assessment 4 - Referred by Hobbs & Aubry (2007)	Dinsmore (1999) [8]	Englund, Graham & Dinsmore (2003) [9]	Kendall & Rollins (2003) [10]	Garfein (2005) [11]	Letavec (2006) [12]	Desouza & Evaristo (2006) [13]	Hobbs & Aubry (2007) [14]	Gartner - Fitzgerald (2008) [15]	Hill (2008) [16]	Hobbs, Aubry & Thuillier (2008) [17]	Kerzner (2009) [18]	Pinto, De Matheus Cota & Levin (2010) [19]	Gartner PPM Predicts (2010) [20]	Crawford (2011) [21]	Unger, Gemünden & Aubry (2011) [22]	Hubbard & Dennis (2012) [23]	PMI Pulse of Profession (2013) [24]	Müller, Glückler & Aubry (2013) [7]	Hubbard & Bolles (2015) [25]	Tsaturyan & Müller (2015) [26]	occurrence	before 2010	before 2012
Advanced PMO									x												1	1	0
Basic PMO				x					x							x					3	2	1
Business PO																		x		x	2	0	2
Business Unit PMO										x		x		x			x		x		5	1	4
Center of Excellence	x	x					x	x	x							x	x		x		8	5	3
Change Operations													x								1	0	1
Coach						x															1	1	0
Consulting PMO					x					x											2	2	0
Controller														x	x						2	0	2
Coordinator															x						1	0	1
Country PMO																		x			1	0	1
Customer Group PMO											x										1	1	0
Delivery Services			x													x					2	1	1
Division PMO																			x**		1	0	1
Enterprise PMO			x	x				x		x	x	x	x	x		x	x*		x		12	6	6
Federated PMO								x													1	1	0
Functional PMO											x										1	1	0
Global PMO																		x			1	0	1
Headquarter PMO																		x			1	0	1
Information Manager						x										x					2	1	1
IT PMO										x			x			x		x		x	5	1	4
Knowledge PMO					x	x															2	2	0
Mature PMO				x																	1	1	0
New Prod. Dev. PMO																x					1	0	1
Portfolio MO																x					1	0	1
Program MO	x	x					x	x		x		x				x	x		x**		9	5	4
Project Coaching			x																		1	1	0
Project MSIO																		x		x	2	0	2
Project Office				x					x				x				x		x		5	2	3
Project Repository			x																		1	1	0
Project Support Office	x	x					x	x								x	x		x		7	4	3
Regional PMO																		x			1	0	1
Standards PMO					x				x												2	2	0
Strategic Project Office																x		x		x	3	0	3
Supporter						x									x						2	1	1
Business PMO										x											1	1	0
Technical PMO										x											1	1	0
Planning PMO										x											1	1	0
Summary																					**95**	**46**	**49**

Appendix B.

Group	Source: / Service Groups:	[5]	[24]	[27]	[14]	[28]	[29]	[30]
1	Managing practices [5] Standards, Methodologies, Processes [24] Knowledge Management [24] Organizational Change Management [24] Stability in processes [27] Flexibility / adaptation / innovation in project management [27] Assessment by external entities [27] Links with external environment [27] Readiness [27] Development of skills and methodologies in project management [14] Gathering data about project progress and producing reports [29] Developing standards and processes [29] Encouraging (or enforcing where necessary) the use of those standards and processes [29] Developing and maintaining PM standards and methods [30] Developing and maintaining project historical archives [30]	x	x	x	x		x	x
2	Providing administrative support [5] Administration and support [24] Providing project administrative support [30]	x	x					x
3	Monitoring and controlling projects [5] Project/Program Delivery Management [24] Control [27]Profit [27] Productivity [27] Monitoring and controlling of Project performance [14] Managing resources for projects [29]	x	x	x	x		x	
4	Training and consulting [5] Talent Management [24] Value of human resources working in a project [27] Organizational learning [14] Knowledge transfer and learning [28] Team Management [28] Delivering training and mentoring to project team members [29] Tracking and managing project benefits [29] Providing human resource/staffing assistance [30] Providing PM consulting and mentoring [30] Providing or arranging PM training [30]	x	x	x	x	x	x	x
5	Evaluating, analyzing and choosing projects [5] Portfolio Management [24] Governance and Performance Management [24] Strategic Planning [24] Planning in goals to reach [27] Efficiency [27] Growth [27] Conflict resolution and search for cohesion [27] Output quality [27] Information and communication management [27] Managing multiple projects [14] Strategic Management [14] Project Portfolio Management [28] Communication Management [28] Managing dependencies across multiple projects [29]	x	x	x	x	x	x	

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Qualitative analysis of electrical-related change orders on university projects

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Abstract

Electrical construction is ubiquitous on building construction projects. Quantitative change order analysis on building construction projects at two American universities showed that electrical change orders were disproportionately high (11-16%) as compared to general contracting (5-10%) or mechanical (5-8%) construction-related change orders, on a percentage of contract value basis. The purpose of the research described herein was to qualitatively analyse electrical change order descriptions on completed building construction projects to discern why this variation exists. The descriptions for 1,214 change orders (associated with 215 projects completed over a seven-year period) were collected and categorized based on the 20 separate reason codes. The reason codes associated with access control/security, interior lighting, circuitry, and low voltage wiring were found to have the highest prevalence. Also, the analysis showed that many electrical change orders were related to work items accounted for by the project team during preconstruction, but not contracted for during the initial tendering stage. Hence, these additional costs, which account for approximately half of the electrical change orders (as a percentage of contract value) were changes to the electrical scope of work as originally contracted, but not changes to the project itself. The results of this analysis show the value of qualitatively tracking (through codes or other methods) change orders, as opposed to purely tracking costs.

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Keywords: Change orders; public construction; electrical construction

1. Introduction

The usage of change orders to address unexpected occurrences, owner desires, and project realities is commonplace on almost every construction related undertaking. Change orders are rarely seen in a positive light; considered a necessary evil at best. Changes after the start of construction commonly lead to project cost and schedule overruns, as well as the heightened possibility of litigation between project stakeholders.

The limited availability of funds for capital investment requires owners to maximize the effectiveness of every dollar spent on construction-related expenditures, especially public owners such as school districts, municipalities, departments of transportation, and public universities. Understanding the prevalence and root causes of changes in an owner's construction program are the first steps to proactively mitigate the quantity and impact of change orders on future projects, as project planning and budgeting activities can be focused towards problem areas. This paper discusses a study of electrical construction-related change orders associated with a set of capital projects completed at a public university in the United States. The research methodology and results are discussed. Results of the study uniquely contribute to the existing body of change order research knowledge through a reproducible methodology for examining change orders on a specific and ubiquitous scope of work (i.e., electrical construction) found on almost all building construction projects.

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2. Literature Review

O'Brien (1998)[1] defines a "change order" as a formal change to a construction contract that includes a change in work, cost of work, or time to perform work. These scope, cost, and schedule changes are typically additions to the originally contracted scope of work but may be deletions. Sun and Meng (2009)[2] provides a broader definition, stating that a change is "an alteration to design, building work, project program or other project aspects caused by modification to pre-existing conditions, assumptions or requirements." Many authors assert that changes (i.e., change orders) are a certainty or inevitability on all construction projects [1, 3, 4, 5, 6]. Hanna et al (2007)[5] posits that for a project to not have any changes, the design, coordination, and communication on the project would have to be perfect, which is simply not possible.

Change orders have been widely researched by both academics and practitioners. Sun and Meng (2009)[2] provides a taxonomy of change order research, summarizing 101 journal papers that had been published between the years of 1985 and 2006. The change order research tract has been prevalent most likely because, as stated by Taylor et al. (2012)[8], "change can make life frustrating for project stakeholders, and many projects experience significant performance degradation because of change." These frustrations are due to the propensity of changes to cause time and cost overruns, disruptions, and disputes [2] as well as being detrimental to contractor productivity [5, 7, 9, 10, 11, 12]. Riley et al. (2005)[13] assert that two types of change orders exist; owner generated change orders, which are issued when an adjustment to the project scope, design, or detailing are required by the owner, and field generated change orders, which arise when problems and conflicts are detected in the field that require a re-design or reconfiguration of the design. Sun and Meng (2009)[2] also assert that change orders can be influenced by external factors (e.g., environmental, political, social, economical, technological), organizational factors (e.g., process, people, technology), and project specific factors (e.g., client generated, contractor/subcontractor generated, project structure). Change orders are seen to have many general causes, such as the uniqueness of each project and the difficulty in predicting the future [6], the limited time and money resources available for planning, executing, and delivering projects [9], project complexity, and the inherent uncertainty of financial performance, development funding, and control of costs and schedule on constructed facilities [14]. Specific root causes of change orders are numerous, and can include: design errors, concurrent design and construction, ambiguous design intent, design coordination issues, unexpected site conditions, weather conditions, owner directed changes in scope, project delays/suspensions, project acceleration, hidden site conditions, differing site conditions, premature tender documents, substitution of products from the specifications, force majeure, and contract item overruns [4, 6, 8, 9, 15, 16, 17, 18, 19, 20, 21].

Collins (2012)[22] describes a study of change orders on 215 multi-prime design-bid-build projects completed by a public university in the United States over a 12 year period. The three main prime scopes of work studied were (1) general contracting, (2) mechanical contracting, and (3) electrical contracting. The results of the study are provided in Table 1 below. As shown, 506 total contracts (total meaning the sum of all prime contracts) were let, with a value of over $190 million. Nearly $21 million-worth of change orders were issued on these contracts, averaging 10.61 percent of the contract value. Mechanical contracting had the lowest change order percentage, at 8.55 percent. The most prevalent scope of work, general contracting, had the mid-average change order percentage at 9.96 percent, and the least prevalent scope of work, electrical contracting, had the highest change order percentage, at 16.09 percent. Collins (2012)[22] noted an area of future research to be determining why electrical-related change orders occur at a higher rate than other major prime scopes of work through a qualitative analysis of change order descriptions (i.e., stated reasons for the changes themselves.)

Table 1 – Summary of results from Collins (2012)[22]

	All Contracts	General Contracting	Mechanical	Electrical
Total number of contracts	506	216	150	140
Total value of contracts	$193,869,389	$105,973,492	$54,327,485	$33,568,412
Average contract value	$383,141	$490,618	$362,183	$239,774
Total number of change orders	2,030	951	565	514
Total value of change orders	$20,567,095	$10,522,049	$4,642,867	$5,402,179
Average amount per change order	$10,131	$11,096	$8,217	$10,510
Average change order percentage	10.61%	9.96%	8.55%	16.09%

3. Research Objective and Methodology

The objective of the study described herein was twofold: to (1) duplicate the research methodology described in Collins (2012)[22] on a separate set of construction projects completed by a public university in the United States to compare change order prevalence, and (2) perform a qualitative analysis of electrical construction-related change orders to discern the reasoning for these change orders.

The specific steps of the research methodology for this study consisted of:

1. Collect and compile cost and change order data (through analysis of completed project cost reports) on a set of projects completed by a public university in the United States. The project data would be categorized by the prime scope of work.
2. Analyze the data to determine the total and average contract amounts for each of the prime scopes of work, along with the total and average amounts of change orders attributed to each scope.
3. Collect and compile qualitative data (i.e., change order descriptions) on electrical construction-related change orders, if the analysis described in step two of the methodology showed that electrical construction-related change orders were prevalent.
4. Analyze the qualitative data to conclude what the specific drivers were for the electrical construction-related change orders.

4. Results

4.1 Quantitative Analysis

The authors reviewed historical cost reports for 215 projects completed by a public university in the United States over a seven-year period. The contracts were broken down into the three main scopes of work listed in Collins (2012)[22]. A summary of the results is provided in Table 2.

As shown, 302 total contracts (total meaning the sum of all prime contracts) were let, with a value of over $621 million. Over $35 million-worth of change orders were issued on these contracts, averaging 5.68 percent of the contract value. Mechanical contracting had the lowest change order percentage, at 5.13 percent. The most prevalent scope of work, general contracting, had the mid-average change order percentage at 5.39 percent, and the least prevalent scope of work, electrical contracting, had the highest change order percentage, at 11.4 percent.

It should be noted that the university projects used in this study were contracted using a single-prime project delivery method, as opposed to a multi-prime project delivery method, as was the case in Collins (2012)[22]. Hence, a majority of the projects are categorized as general contracting, even though mechanical and electrical-related construction was part of that scope of work. The mechanical and electrical contracts listed in Table 2 are for those projects that solely had mechanical and electrical construction.

Table 2 – Summary of results				
	All Contracts	General Contracting	Mechanical	Electrical
Total number of contracts	302	208	70	24
Total value of contracts	$621,145,801	$504,462,754	$82,327,320	$34,355,727
Average contract value	$2,056,774.18	$2,425,301.70	$1,176,104.57	$1,431,488.63
Total number of change orders	1,214	812	256	146
Total value of change orders	$35,310,617	$27,172,533	$4,220,067	$3,918,017
Average amount per change order	$29,086.18	$33,463.71	$16,484.64	$26,835.73
Average change order percentage	5.68%	5.39%	5.13%	11.40%

4.2 Qualitative Analysis

The authors determined that performing a qualitative analysis of the electrical change orders was warranted, as the prevalence of electrical construction-related change orders had a similar magnitude to the results of Collins (2012)[22]. The qualitative analysis would be used to determine the reasoning for the electrical change orders (i.e., was there a specific reason or reasons that led to electrical construction-related changes orders being significantly higher than the other prime scopes of work.) The authors developed a set of 20 categories, described in Table 3 (listed in alphabetical order.) The categories were based on specific electrical construction work items and on other necessary category types, such as ‘allowances’ or ‘other.’

Table 3 – Change order categories and their descriptions

Category	**Description**
Access control/security	Video surveillance, security systems, and access control
Allowances	Change to the original contracts resultant from unused unit costs
Audio Visual (A/V)	All audio/visual systems, such as televisions and projectors
Circuitry	Change to circuitry, conduit, or cable pulls
Design changes	Design changes or revisions after the start of construction
Devices	Includes electrical outlets, boxes, switches, and any other electrical devices
Electrical equipment	Electrical equipment such as step-down transformers, main switch gear
Exterior lighting	Site lighting, street lighting, and parking lot lighting
Interior lighting	Wiring and fixtures related to interior lighting
HVAC and elevator	Electrical controls for HVAC or elevator equipment
Life safety	Life-safety inspections, fire alarm systems, radio alarm systems, and emergency communications
Lightning Protection	Changes resultant from lightning protection items
Looking ahead	Changes to a current project to accommodate an anticipated future project
Low voltage	Changes related to telecommunications, data, information technology, and internet/ethernet
Non-electrical	These were non-electrical changes to electrical contracts
Not enough detail	Change orders with descriptions not detailed enough to be put into any specific category
Other	Items not related to any of the other categories
Owner furnished items	Changes associated with items provided by the owner, but installed by the contractor
Primary service	Changes to the main electrical feed, as well as those associated with generators
Sitework	Sitework-specific changes

The authors chose to assess each of the 20 categories based on three components: (1) their rank based on prevalence (i.e., occurrence) as compared to the other categories, (2) their rank based on the total dollar amount of all changes that fell into the specific category, and (3) their rank based on the average dollar amount of all changes that fell into the specific category. The authors determined that the prevalence of the change order categories should be analyzed along with their cost components to assess the overall magnitude of the changes. For example, many change orders may fall into one category, but the total or average cost of the changes could be minimal. Other changes may not be as prevalent but have a higher attributed total or average cost. The authors completed the analysis using a weighted scheme, where the total score for each change order category would equal three-times the rank of the change order's occurrence, plus two-times the change order's total dollar amount rank, plus one-times the change order's average dollar amount rank. An example of this scoring scheme (for audio visual-related change orders) is provided below in Figure 1. The ranking of each change order category used the methodology of the higher the occurrence, total value, or average value, the lower the rank score. For example, the category with the highest number of occurrences would receive a rank of one, and the category with the lowest number of occurrences would receive a rank of 20. Hence, the lower the total score, the greater the magnitude of the change order category.

Figure 1 – Example of Weighted Ranking System for Audio Visual Category

A	B	C	D	E
Change Order Category	Ranking with respect to total number of occurrences	Ranking with respect to total dollar amount	Ranking with respect to average dollar amount per occurrence	Weighted Ranking = (Column B x 3) + (Column C x 2) + (Column D)
A/V	15	15	9	84

A summary of the rankings for all of the change categories is provided below in Table 4. As shown, access control/security, interior lighting, circuitry, not enough detail, life safety, and low voltage have the lowest scores, meaning that on a weighted basis, those change order categories carried the highest overall magnitude to the projects used in the study.

Table 4 – Weighted Ranking of Change Order Categories

Category	Number of occurrences rank	Total dollar amount rank	Average dollar amount rank	Score
Access control/security	6	1	2	22
Interior lighting	3	3	7	22
Circuitry	1	4	14	25
Not enough detail	9	2	3	34
Life safety	2	6	17	35
Low voltage	5	5	10	35
Devices	4	9	15	45
Sitework	7	10	12	53
Exterior lighting	12	8	6	58
Design changes	14	7	5	61
HVAC and elevator	8	13	13	63
Electrical equipment	10	12	11	65
Looking ahead	18	11	1	77
A/V	15	15	9	84
Primary service	16	16	8	88
Owner furnished items	19	14	4	89
Other	13	17	18	91
Allowances	11	20	20	93
Non-electrical	17	18	16	103
Lightning protection	20	19	19	117

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5. Discussion of results

The category of access control/security was ranked sixth with respect to total number of occurrences, first with respect to total dollar amount, and second with respect to average dollar amount per occurrence. The authors noticed a recurring theme in the detailed descriptions of change orders in this category, that many of these change orders included incorporating scope packages into the respective projects that could have been included in the original project bid documents but were not for reasons not apparent in the data. For example, the most expensive item from this category was the incorporation of three construction change directives into the project, noted as "Furnish and install all wiring and devices for Access Control and CCTV." The change order is adding a security and access control package to the project after the start of construction. This scope of work is typical for projects completed by the University and would have been included in the total project budget, hence could have been included in the original bid documents.

An analysis of descriptions for change orders in the interior lighting category showed similar results. For example, the two most expensive change orders in this category were attributed to the Owner requesting that the electrical contractor add to their scope of work the lighting fixture package that was originally an Owner-furnished item. Again, the Owner would have included the cost for the lighting fixture package in their total project budget but chose not to include this with the electrical contractor's original scope of work.

The categories of circuitry and low voltage showed more mixed results upon further detailed review. Circuitry change orders were relatively inexpensive when they occurred, but they occurred more often than change orders from any other category by far. The occurrences, as per the detailed descriptions, included adding circuitry to items added to the project (either by the owner or through design clarifications), rough-in of power circuit for future work adjacent to the project at hand, and changes to cover unforeseen conditions realized after the start of construction. Telecommunications circuitry (included in the low voltage category) also required several change orders related to additional work for future projects. Changes related to unforeseen conditions would be expected to be significant, due to the nature of work completed by the University (and most Universities) being renovation in nature as opposed to new construction, but additional work related to future projects would not be expected.

The takeaway from this analysis was that while electrical change orders, from a quantitative perspective, seem disproportionately expensive, most of the largest electrical change orders were from items that would have been accounted for in the Owner's original budget, and were therefore not what would be considered "bad" change orders. The author's estimate that if change orders of this nature were removed from the analysis, the overall change order percentage would drop by approximately half, bringing the overall electrical change order percentage in line with the mechanical and general contracting prime scopes of work. Another main takeaway is the value of complete a qualitative analysis of change orders to complement a quantitative analysis. As shown, a purely quantitative analysis can be deceptive, and not allow Owners to focus towards improving project change performance of items truly in need of addressing on future projects.

6. Conclusions, Limitations, and Future Research

Owners must be diligent with their funds if they are to get the maximum value from their projects. Change orders are pervasive in the construction industry, but as shown, are not always detrimental to an Owner's overall project budget. Many change order items (as least according to the data analysed in the described research project) are a product of Owner's choosing to push-off contracting certain items until after the start of construction or choosing to incur costs on current projects for the betterment of future works. The overall magnitude of such changes can be significant. The analysis also shows the value of qualitative analysis over purely quantitative analysis. It is paramount for decision makers to fully understand the full scope of what may be included in any kind of quantitative analysis, as figure can be misleading.

This study was limited to a set of projects completed by one public university owner in the United States. The results of the study may not be representative of every Owner's construction program. The change orders of general contracting and mechanical scopes of work were also not analysed as part of this project, only electrical construction-related change orders. Future research should seek to again replicate this type of change order analysis with another public university owner, or an owner with a significant construction program that includes a substantial amount of renovation work. Change orders attributed to general and mechanical contracting should also be studied to discern how those changes align with the results of the study described here.

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Risk sharing in the construction work contracts

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Abstract

By signing a contract for construction works each of the parties assumes a specific scope of responsibility. In practice, there are numerous examples of contractual provisions that violate the parties' safety and the balance of fair and even distribution of risk. Asymmetry in risk allocation in construction contracts and its consequences is the most common cause of disputes between the parties. The article presents the issue of risk distribution and its consequences on the example of selected construction contracts provisions.

Keywords: contractor; contract for construction works; investor; ordering party; risk;

1. Introduction

The preparation and implementation of a construction investment project is a complex activity covering a wide range of tasks of technical, legal [1,2,3] and economic nature. The implementation of a construction investment is also dependent on numerous administrative, civil and legal requirements [1]. The complex and specific nature of the construction investment process makes it necessary to precisely establish the relationship, rules of cooperation and commitments of the involved entities [4,5]. From point of view of risk sharing between the parties involved in the project, it becomes particularly important to appropriately define the content of a construction contract. The result of its conclusion is the acceptance of certain obligations and their consequences by each of the entities. The aim of the proportional distribution of risk is to ensure the strategic security of the parties [5].

2. Construction works contract

The contract for construction works, constituting an essential element of the construction investment process, is regulated in the provisions of art. 647-658 of the Civil Code (CC) [1]. By signing the contract for construction works, the investor obliges to perform the activities required by the applicable regulations related to the preparation of works, and the contractor - to hand over the facility agreed in the contract, built in accordance with the design and principles of technical knowledge. The construction contract is of mutual nature - each party is entitled to the performance and at the same time is obliged to provide it, if the provision of one of the parties of the contract is equivalent to that of the other [6]. The cooperation of participants in the construction investment process can be carried out in various ways. Relations between entities define the content and scope of the design work, geological works, geodetic and cartographic works, investor's supervision or author's supervision, investment substitution, construction works, subcontracting or partial subcontracting, supply of equipment, etc. [7]. The subject of this article are contracts for construction works in the "build" and "design and build" framework in public and non-public procurement.

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According to art. 353[1] of the Civil Code [1]: *"Contracting parties may establish a legal relationship at their own discretion, as long as its content or purpose does not conflict with the nature of the relationship, the act or the rules of social coexistence."* This principle gives the parties the freedom to decide on the conclusion of the contract and its content. Due to the fact that neither the Civil Code [1], nor any other legal act indicates exactly what provisions should be used in the text of the contract in order to achieve a proportionate and rational distribution of risk between entities, it is difficult to construct such provisions correctly. There are contracts that constitute an extensive violation of the principle of social coexistence and equality of parties through unequal distribution of risk [8,9].

The analysis of the content of selected construction contracts, allows to indicate the most common sources of disputes between the parties. These include [6,8]:

- the lack of correct definition of the contract parties, the scope of their rights and obligations, persons representing the parties, the subject of the contract, the scope of the parties' obligations and responsibility,
- the lack of provisions regarding the rules of performing additional and replacement works and their settlement,
- the lack of provisions regulating the introduction of changes to the project documentation at the stage of construction works implementation [10,11],
- the lack of precise arrangements regarding the calculation of contractual penalties for failure to meet the deadline (for delay),
- the excessive amount of contractual penalties on contractor’s side,
- the lack of detailed specification of the due date of works and specific milestones,
- the failure to specify the scope of the necessary documentation and the manner of informing the contractor about the activities, requiring his notification or consent,
- the lack of precise specification of the form of settlement (flat rate, cost estimate),
- the lack of detailed regulations regarding the rights under the guarantee and warranty,
- imprecise provisions regarding the contractual parties' security, e.g. the right to withdraw or terminate the contract, compensation, guarantee deposits, etc.,
- the lack of detailed provisions regarding procedures to be followed, for example, for payment of remuneration, reporting defects, accepting works, etc.,
- inconsistency between the provisions of the contract and the provisions contained in its annexes [12].

The above reasons constitute a source of conflicts, sometimes also disputes, often resolved in court [8].

It is possible to indicate the following "groups" of contractual provisions, violating the law or aimed at avoiding it [13]:

1. Imposing on the contractor the obligation of a detailed verification of project documentation or PFU and reporting detected defects at the stage of submitting offers - transferring to the contractor the statutory obligation of the contracting authority. The contracting authority is responsible for the correct preparation of the tender procedure (including the correct project documentation or PFU), and the contractor at the tender stage is not obliged to thoroughly check the delivered project to detect its defects. It is obvious that at the stage of the tender, the contractor does not need to have specialist knowledge in the field of design – he/she must only be able to read the SIWZ correctly and prepare the offer in accordance with the requirements of the ordering party.
2. Transfer of responsibility for defects in the project documentation or PFU to the contractor of construction works after signing the contract. This may mean the need to redesign or improve some structural elements, and consequently extend the original scope of the contract after it is signed, without changing the original price. It is the responsibility of the ordering party to describe of the subject of the order so that the contractor has no doubts about the scope of the contractual obligation and can fulfill the order in accordance with the submitted offer.
3. Charging the contractor with the task of supplementing missing drawings and/or the project documentation required for the implementation of the contract subject. In accordance with applicable law, delivery of a complete and properly prepared project documentation is the responsibility of the ordering party.
4. Imposing on the contractor, at the project planning stage, the detailed examination of the area of the future construction (including checking geological and geotechnical conditions of the ground, geodesic foundations, geodetic inventory of underground and ground utilities and existing facilities). This information should be

provided by the ordering party. Such provision coming from the ordering party "informs" the contractor about investor's failure to comply with the obligation to properly prepare the tender procedure (including the incorrectly prepared documents). Consequently, it may indicate future obstacles in the execution of the contract.

5. Obliging the contractor to execute the orders of the investor's supervision or Engineer (in contracts executed under FIDIC conditions), going beyond the scope of the contract, not being the result of defective or illegally performed work, and/or obliging the contractor to perform works that were not included in the scope of the order and/or which the ordering party has not foreseen at the stage awarding the contract.

   This allows to extend the scope of the contract after it has been signed. This type of demands is often based on the reference to the flat-rate nature of remuneration. It is a contractor's obligation to predict and include in the proposed price the size and costs of work unambiguously and comprehensively described by the ordering party. The contractor's remuneration concerns only the scope of the construction works contract. The agreed remuneration is binding for the parties only in the case of a proper description of the order subject (i.e. the scope including all requirements and circumstances that may affect the preparation of the offer). According to the Public Procurement Law (PPL), the scope of the contract is identical to the obligation included in the offer, and the content of the offer is consistent with the SIWZ (including, the description of the subject of the contract). At the stage of submitting the offer, the contractor has the right to assume that the scope of the ordered works is correct and complies with the regulations. This means that all contractual provisions transferring to the contractor the risk of carrying out works not covered by the description of the contract are contrary to the PPL and the rules of social coexistence. If during the construction works defects in the description of the contract subject are identified, the contractor should immediately notify the ordering party about the issue and request their cooperation to determine the method of completing the tasks. The contracting authority is obliged to know exactly its requirements at the tender stage and specify their scope in the project documentation (the "build" variant) or PFU (the "design and build" variant). The contractor signing the contract is obliged to perform, within the agreed remuneration, only the scope of works specified in the contracting documents.

6. Charging the contractor after signing the contract with obligations of the ordering party in the process of preparing and conducting the contract awarding procedure. These duties may concern:

   - obtaining the right to use the property for construction purposes,
   - performing soil and water tests,
   - performing the greenery inventory,
   - measurements of road traffic, noise, etc.,
   - performing the inventory of objects if they are subject to reconstruction, demolition, etc.,
   - obtaining consents, permits or agreements and technical conditions related to the connection of facilities to existing water, sewage, gas, electricity, roads networks, etc.

   These activities concern the stage of preparing and conducting the procurement procedure, thus they cannot be transferred to the contractor after signing the contract.

7. Charging the contractor with responsibilities statutorily assigned to the contracting authority, concerning:

   - applying to the authorities for a change of the building permit in case of significant changes to the project,
   - obtaining the use permit,
   - obtaining the consent of the land owners for the provision of land on which the investment will be implemented (transmission easement, e.g. electricity is established only for the benefit of the party who intends to build an electricity network),
   - making changes to the projects provided by the contracting authority (the contractor cannot assume any responsibility for the design and the defects of the prepared documentation, because there is no binding contractual relationship based on which the contractor could claim compensation - the "design and build" framework is an exception).

8. Acceptance of the completed works by the ordering party being dependent on circumstances beyond the contractor's control or unrelated to the construction process. One of the basic obligations of the contracting authority is the acceptance of works (object). The acceptance by the ordering party confirms the fulfillment of the obligation and constitutes the basis for the contractor to demand remuneration.

9. Making the payment of the contractor's remuneration dependent on the completion of tasks by entities that are not parties to the contract.
10. Equating of the deadline of work completion with the date of signing the fault-free final acceptance protocol. The acceptance activity is not an element of construction works and according to the provisions of the order, the acceptance is the investor's responsibility. With the exception when the defects prevent the proper use of the object (of agreed scope) or significantly reduce its value (significant defects). Only the significant defects justify the refusal to accept the works or withdraw from the contract and impact the payment claim for the performed work. Other defects (so-called insignificant) mean completion of the obligation in an improper manner in terms of quality. In this case, the investor may demand removal of the defects within a specified time or adequate reduction of the contractor's remuneration. Detected negligible defects should be removed in accordance with the provisions of the order. The investor's right does not affect their obligation for works acceptance and remuneration payment for the object erected in accordance with the design and principles of technical knowledge.
11. Equating the date of works completion with obtaining a permit to using the facility. The application for a permit for the use of the object is within the scope of the investor's statutory obligations. It is possible only after completion and acceptance of executed works. The contractor has no control over the date when the investor reports the object to as ready to use.

3. Allocation of risk in the construction works contracts - examples

In public procurement, the division of risk between the parties of the contract is the responsibility of the procuring entity to draw up the contract for construction works. In case of large non-public orders, usually the investor also edits the content of the future contract. At the stage of preparing a construction project, usually the contracting entities/investors do not have complete information about the future investment [14]. In order to minimize the effects of unforeseen circumstances and potential risks (e.g. the increase in costs), appropriate provisions in the contracts constitute a form of "risk management" [15,16].

In practice, two groups of provisions appear in the construction contracts. These are:

- entries that constitute an unjustified restriction of the contractor's rights,
- entries that constitute an unjustified extension of the contractor's obligations.

The result of the above provisions constitute a transfer of a large share of the risk to the contractor of construction works and a significant breach of their strategic security [17,18].

Referring to the above classification, the authors present selected examples of provisions included in contracts for construction works in public and non-public procurement (table 1, table 2).

Table 1. Examples of entries that constitute an unjustified restriction of the contractor's rights.

Example	Entry
Example 1	*"The Contractor declares that he/she has familiarized himself with the Project, Construction Permit and other annexes to the Contract and does not raise any objections to them. The Contractor confirms that the documentation in question is complete in terms of substance, form and enables timely performance of all obligations arising from the content of the Contract".*
Example 2	*"The Contractor accepts that he/she will not be entitled to any claims and will waive all possible claims against the Ordering Party for any mistakes, inaccuracies, discrepancies or defects in the Design Documentation, including any claim for payment of any increased costs or payments in addition to a contract price or an extension of time to complete as a result of such mistakes, inaccuracies, discrepancies or other defects in the Design Documentation".*
Example 3	*"In the event of termination of the contract for reasons attributable to the Contractor, the Investor shall not be obliged to pay for the delivered but unmounted devices that are part of the facility's equipment".*
Example 4	*"The Contractor declares that he/she will not take part in other construction projects, the implementation of which could adversely affect the quality and/or timeliness of obligations performance indicated in the content of this Agreement."*

Table 2. Examples of provisions constituting an unjustified extension of the contractor's obligations.

Example	Entry
Example 1	*"The Contractor undertakes to perform for the agreed flat-rate remuneration in the amount of (...) of the full scope of works covered by the project documentation, as well as all works not covered by this documentation, which need to be performed in the course of the works."*
Example 2	*"The Contractor is responsible for the proper planning of the implementation of works and their organization, as well as the coordination of work carried out by Subcontractors indicated by the Investor to carry out selected scope of work related to the investment under separate Contracts".*
Example 3	*"The Contractor shall pay to the Ordering Party contractual penalties for delay in relation to the intermediate dates specified in the Material and Financial Timetable, for each commenced day of delay in relation to the intermediate term, in the amount of 0.05% of the gross remuneration for the performance of the Contract".*
Example 4	*"Optimization of documentation, received by the Contractor, shall consist of: (...) preparation of Replacement Documentation in the scope of inconsistent (technically impossible to implement solutions) between individual volumes of Project Documentation (...), preparation of Replacement Documentation in the case of occurrence discrepancy between the existing state and included in the Design Documentation (...) ".*
Example 5	*"The Contractor is obliged to obtain the rights to have the areas available to which the Investor does not have such a right (...), as well as obtain all other Permits required to conduct the Works".*
Example 6	*"The Contracting authority may request a change in the performance of the subject of the contract, it may consist of performing additional work or omitting some of the work or parts thereof. The amount of remuneration may therefore change ".*

The above examples of contractual provisions are a form of risk transfer to contractor resulting from improper, unreliable and unprofessional preparation of a construction project by the contracting authority/investor.

4. The social dimension of the asymmetry of the risk distribution in the construction works contracts

When analyzing the content of construction contracts in public procurement, attention should also be paid to the social dimension of the disproportionate risk sharing. From the point of view of the effective spending of public funds, the excessive limitation of contracting parties' own responsibility be the violation of the public interest. According to PPL [2] correctly defined conditions of the procedure should allow for the conclusion of the most economically advantageous contract, ensuring the maximization of effects in relation to the incurred expenditures.

Sometimes the reaction of contractors to an extensive inequality of parties, i.e. deprivation of their rights, results in a significant increase of prices of the submitted offers. In other cases, the contractor's lack of experience in assessing the long-term effects of asymmetrical risk sharing results in the loss of their stability and security. As a consequence it is the cause of conflicts, litigation and an obstacle to the proper implementation of the contract subject [4]. Usually the major disruptions in the implementation of the investment result in a significant increase in costs and an extension of the project completion date.

It is possible to indicate examples of actions undertaken by contractors because of a signed contract for construction works that is a threat to their strategic security caused primarily by the need to bear large additional costs when:

- the contractor requests termination of the contract (e.g. where the parties have agreed a lump sum form of settlement and significant risk occurred, the effects of which have not been included in the offer price),
- the contractor declares bankruptcy (e.g. in the case when a significant risk occurred, and its effects exceed the financial capacity of the contractor),
- the contractor incurs higher costs than assumed, and when the work is completed, he takes his claims to court.

The social dimension of the above situations is very clear. Each of the cases in effect generates an additional expense on the part of the ordering party. In the event of termination of the contract or declaration of bankruptcy by the contractor, the contracting entity must make an inventory of the works already completed and carry out procurement procedures again, in the case of a lawsuit - contracting entity may have to bear significant additional costs.

5. Conclusions

A rational and fair division of risk between parties of a construction contract should be preceded by comprehensive identification, analysis and quantification of possible risks and their consequences. It allows for optimal and effective risk identification and determination of the real price for the project implementation. When preparing a model contract for construction works, many investors are convinced that the application of the appropriate provision results in an effective transfer to the contractor the consequences of unforeseen circumstances. However, it should be borne in mind that in some cases such action is ineffective. To ensure the parties' safety within the contract, the risk should be assigned to the entity that is able to manage it better (control, eliminate, limit) and has a real impact on it. It is possible to achieve due to a properly constructed content of the construction contract, close cooperation of the parties and consistent compliance with the provisions defined therein.

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The Development of a Questionnaire Survey to Investigate the Critical Risk Factors in Oil and Gas Pipelines Projects

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Abstract

The scarcity of data about "the probability and severity" of the Risk Factors (RFs) and "the usability and effectiveness" of the Risk Mitigation Methods (RMMs) in Oil and Gas Pipelines (OGPs) are hindering the efforts of risk mitigations in these projects. Consequently, this paper aims to develop a questionnaire survey to collect these require data to analyze the RFs and effectively evaluate the RMMs. Firstly, documents qualitative analysis were carried out to identify the RFs and RMMs in OGPs projects in different countries worldwide. Secondly, an industry-wide questionnaire survey was found to be an effective quantitative approach to analyze the "probability and severity" levels of the RFs and to evaluate the "usability and effectiveness" degrees of the RMMs. A pilot-like survey was significantly needed to improve the clarity of the questions and revise the ambiguous questions. As well as, to add the necessary queries and discard the unnecessary ones. Moreover, the pilot-like survey was used to test the functionality of the rating scales; and to improve the overall design of the survey. This survey filled by a number of experts in OGPs projects; their feedback was found helpful to write the final draft of the survey. The findings of this paper was a questionnaire survey that will be used in ongoing research about mitigating the RFs in OGPs projects. Furthermore, a few authors explained their procedure of designing such survey. Therefore, researchers in this field could use the findings and comments of this to design their surveys.

Keywords: Oil and gas pipelines (OGPs), risk analysis, Risk Mitigation Methods (RMMs), questionnaire survey, pilot-like survey, stakeholders perceptions

1. Introduction

The procedure of risk management in Oil and Gas pipelines (OGPs) projects requires a proper knowledge [1] and verified historical records [2] about the probability and severity levels of the Risk Factors (RFs) that associated with OGPs projects. However, the current methods of RFs analysis are not accurate enough to analyze the probability and severity levels of the RFs. Particularly, in the developed and troubled countries because no database provides verified information about the RFs has been established yet [3,4]. Moreover, up-to-date data about the "usability and effectiveness" degrees of Risk Mitigation Methods (RMMs) are required to manage the safety of OGPs more effectively and to make useful recommendations for OGP's risk management. From the preceding, there is a vital need to collect trusted data about the "probability and severity levels" of RFs and about "the usability and effectiveness degrees" of RMMs.

Therefore, this paper aims to design a questionnaire survey to collect the required data for mitigating the RFs in OGPs projects such as (I) identify the RFs; (II) analyze the portability and severity of the RFs; (III) identify the RMMs and (IV) evaluate the usability and effectiveness degree of the RMMs.

Moving forward in this paper, section 2 was about identifying RFs and RMMs in OGPs projects. Section 3 illuminates the procedure of developing a questionnaire survey. Section 4 shows the final draft of the questionnaire survey. Section 5 discusses the findings of this paper. Finally, section 6 highlights the conclusions.

2. Identifying the RFs and RMMs

Worldwide qualitative documents analysis were carried out to identify the RFs and RMMs in OGPs projects in different countries. Extra attention was made to identify the RFs in the insecure areas, the findings of these investigations are shown in Table 1.

Table 1. The identified RFs and RMMs in OGPs projects from the documents analysis.

A- RFs	**Author**
Thieves	[5,6]
Publics' legal and moral awareness	[2]
The education and poverty levels in OGPs areas	[5]
Leakage of sensitive information	[7]
Threats to staff	[8]
Sabotage and Terrorism	[5]
Accessibility of pipelines	[9]
Conflict over land ownership	[10]
Insecure areas	[9]
Vehicle accidents	[2]
Animal accidents	[11]
Geological RFs	[12]
Lack of regular inspections and maintenance of OGPs	[5]
The opportunity to sabotage exposed pipelines	[8]
Lack of compliance with the safety regulations	[5,12]
Weather conditions and natural disasters	[5]
Inadequate risk management approaches	[5]
Non-availability of warning signs	[13]
Weak ability to identify and monitor the RFs	[5]
Corrosion and lack of anti-corrosive action	[5]
Shortage of modern IT services	[5]
Design, construction and material defects	[12]
Hacker attacks on the operating or control systems	[9]
Operational errors	[5]
Corruption	[5]
Few researchers about this problem	[5]
Lawlessness	[2]
Lack of proper training schemes	[5]
No proper attention from the stakeholders	[5]
Lack of historical records and data about RFs	[5]
B- RMMs [8]	
Cathodic protection, painting, isolation layers and other methods of anti-corrosion	
Lay the pipelines underground rather than above ground	
Advanced IT system and modern equipment to monitor the RFs	
Proper inspection and maintenance	
Proper training	
Avoid insecure areas	
Anti-terrorism planning and design	
Avoid the registered RFs	
Protective barriers	
Government-public cooperation	
Warning signs near the pipelines and marker tape above the pipeline	

However, the results of the investigations in Table 1 cannot provide information about the "probability and severity" levels of the RFs and the "usability and effectiveness" degrees of the RMMs in a specific country. Especially, in the countries which have limited registrations abut RFs and limited studies about the safety of OGPs such as Iraq. Therefore, this paper was aimed to design a questionnaire survey to engage with the stakeholder in OGPs projects to obtain consensus perceptions about that RFs and RMMs in OGPs projects. Because the perceptions of stakeholders are based on real experience in OGPs projects, which makes them qualified to monitor the RFs in OGPs projects [14] and to evaluate the RMMs.

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3. Structure Development of the Questionnaire Survey

Questionnaire surveys are one of the most widely used data collection methods to understand an attitude or behavior. As well as, this method of data collection enables the researchers to write the formulation of precise queries for respondents whose views are needed [15]. For an accurate questionnaire survey, the design of the survey went through different steps; the flowchart of developing the questionnaire survey was illuminated in Figure 1.

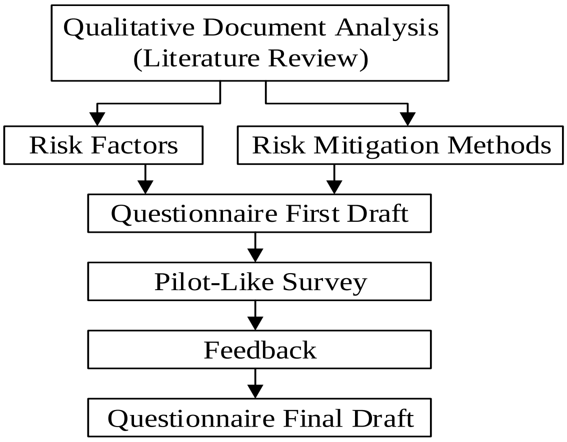

Figure 1: The flowchart of developing the questionnaire survey.

An extensive review of the literature was accomplished to determine the variables of the survey questionnaire that are the RFs and RMMs (see Table 1). Firstly, Table 1 was adopted to write the first draft of the questionnaire (see Table 2). Secondly, send this draft to a number of experts in OGPs projects in Iraq to get their feedback about the survey. The final step is to use work with the experts' feedback to write the final draft of the survey.

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Table 2: The first draft of the questionnaire survey.

Section I: Introduction and the Participants' Demographic Information	
Introduction	A 200 words introduction about the research and the survey
Question 1	Education Degree
Question 2	The participants' occupation in OGPs
Question 3	The participants' experience in OGPs
Section II: The Critical Risk Factors	
Question 4: How often are the following factors affecting the third party disruption? (Always, Very often, Often, Sometimes, Seldom, Do not happen at all and Undecided) **(Seven-Points Likert scale)**	
Security and social *	Public law legal and moral awareness
	Public socio-political
	Thieves
	Terrorism and sabotage
	Staff threats, kidnapped and murdered
	Leakage of sensitive information
Pipe's location (Topography) *	Geographical location like "Hot-Zones"
	Conflicts over land ownership
	Accessibility to pipelines
	Geological risks
Occupational safety and environment *	Lack of compliance with the safety regulations
	Non-availability of warning signs
	Sabotage opportunities arising due to above-the-ground pipeline
	Natural disasters and weather conditions
	Traffic accidents
	Animals attacks
Technical *	Shortage of the IT services
	Corrosion; lack of cathodic protection
	Pipe's type, age, diameter and length
	Hacker attacks on the operating or control system
	Lack of regular inspection and maintenance
	Operational errors
	Design and manufacturing defects
Roles and regulations *	Government roles and the laws are not sound
	Lack of accidents historical records
	Lack of proper training schemes
	Limited researchers are dealing with this problem
	Stakeholders are not paying proper attention
	Inadequate risk management methods
	The weak ability to identify and monitor the threats
	Corruption
Question 5: Please, rank the above factors from (1-5) in order of the severity on the pipeline. Where 1 means the most critical and 5 is the less critical.	
	Security and social
	Pipe's location (Topography)
	Occupational safety and environment
	Technical
	Roles and regulations
Question 6: Please, write any other risk factors that have not mentioned in this survey. **(Open-ended question)**	
Section III: Risk Prevention Methods	
Question 7: How often are the following risk production methods used? (Always, Very often, Often, Sometimes, Seldom, Do not use at all and Undecided) **(Seven-Points Likert scale)**	
Early stages of the projects *	Risk registration
	Threat assessment
	Anti-terrorism design
	Avoid "Hots-Zones"
	Move to an underground pipeline
	Anti-corrosion isolation and cathodic protection
Early stages of the projects *	Patrols
	Professional remote monitoring
	Government-public cooperation
	Proper training
	Warning signs and marker tape above the pipeline
	Protective barriers and perimeter fencing
	Proper inspection, tests and maintenance
Question 8: What are you prefer?	
	The aboveground pipeline, despite it can often provide sabotage opportunities.
	The underground pipeline, despite the constructions and maintenance difficulties.
Question 9: Please, rank the stages of the project from (1-3) in order of the priority to mitigate pipelines third party disruption. Where 1 means the highest priority and 3 is the less priority.	
	Planning & design
	Construction
	Operation
Question 10: Please, write any other risk prevention method in your opinion that has not been mentioned. **(Open-ended question)**	
Question 11: Please, if I need additional information, can I contact you? Please provide any contact information if you agree. **(Open-ended question)**	

*Note: these are subtitles.

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The first draft of the survey had three sections as follows. Section I was about a brief summary about the research to explain the aim of this research, the purpose of the survey, a notification that the respondents will be treated anonymously, and the research's contact details “email and the mobile number" in case of any inquiries. Questions 1 to 3 were asked about the participants’ degree of education, occupation and experience respectively. Section II had three questions to evaluate the RFs and to add more RFs for the study. Finally, section III had five questions to evaluate the RMMs and to add more RMMs for the study.

A pilot-like test refers to a pre-test that estimates the response rate of the targeted sample. The purpose of a pilot-like is to spot certain aspects of the survey that needs refinement. Also, it helps the researcher to predict the factors that might affect the validity of the survey to avoid them [16]. Over and above, the first draft of the survey was adopted in a pilot survey to assess the clarity of the questions, the functionality of the rating scales and about the overall consistency and design of the questionnaire. The survey was written in English and Arabic languages, and it was up to the respondents to choose the language. As Blaxter et al. [15] recommended, the pilot survey was sent to 10 experts in OGPs projects in Iraq for an informal discussion about the survey. After one week, six of these experts filled the pilot survey as shown in Table 3.

Table 3: Experts’ general information.

Education		Experience		Experience (years)	
No degree	2	a member of a construction team	5	6 to 10	1
Bachelor degree or Higher diploma	2	a researcher or student	1	11 to 15	2
Masters or PhD	2			More than 15	2
Total	6	Total	6	Total	6

Working with comments from experts was as follows. The subtitles are making the survey long. Therefore, the subtitles have been removed from the final survey. The pilot-like survey missed evaluating the severity levels of the RFs and the effectiveness degrees of the RMMs. For that purpose, questions 5 “to analyze the severity of the RFs” and 9 to “evaluate the effeteness of the RMMs” were added in the final survey. Likert scale was used in this survey because it one of the most and widely used scales for despite critiques like previous studies were reported the respondents might be biased or attempt to portray the issues in a more personal matter [17-19]. The authors wanted to analyze the RFs and evaluate the RMMs more effectively by using a seven-point Likert scale. However, the participants complained that it was confusing to them. Thus, a five-point Likert scale was used in the final survey, which is more comfortable for follow as they suggested. After phone calls with the participants, the clarity of the survey overall was improved, the questions that found to be vague were revised or discarded, the lists of RFs and RMMs methods were revised for better clarity. Some of these RFs and RMMs have been paraphrased to make sure that these lists fit with the aim of the ongoing research about mitigating the RFs in OGPs projects in Iraq. Some typos, spellings and grammar mistakes were spotted in the pilot survey and changed in the final draft. The statistical analysis of the pilot like survey were used to test the functionality of the survey for the research. From the preceding, the final draft of the survey was written as explained in section 4.

4. The Final Draft of the Questionnaire Survey

The final draft of the questionnaire survey was shown in Table 4.

Table 4: The final draft of the questionnaire survey.

Section I: Introduction and the Participants' Demographic Information	
Introduction	A 200 words introduction about the research and the survey
Question 1	Education Degree
Question 2	The participants’ occupation in OGP projects
Question 3	The participants’ experience in OGPs projects

Section II: Analyzing the Risk Factors	
Please, rank the following risk factors which are facing the oil and gas pipeline projects on the scale of probability and severity. Please note, to see the two scales, You may need to move the screen to the right or the left. Question 4: Risk factors probability scale. (Almost certain, Likely, Possible, Unlikely and Rare) **(Five-Points Likert scale**) Question 5: Risk factors severity and consequence scale. (Catastrophic, Major, Moderate, Minor and Negligible) **(Five-Points Likert scale)**	
	Terrorism & sabotage
	Corruption
	Insecure areas
	Lawlessness
	Thieves
	Corrosion & lack protection against it
	Improper safety regulations
	Improper inspection & maintenance
	Publics' legal and moral awareness
	Weak ability to identify & monitor the threats
	Stakeholders are not paying proper attention
	Lack of proper training
	Exposed pipelines
	Shortage of the IT services & modern equipment
	Limited warning signs
	The pipeline is easy to access
	Lack of risk registration
	Little researches on this topic
	Design, construction & material defects
	Conflicts over land ownership
	Threats to staff
	The education and poverty levels in OGPs areas
	Operational errors
	Inadequate risk management
	Leakage of sensitive information
	Geological risks
	Natural disasters & weather conditions
	Vehicles accidents
	Hacker attacks on the operating or control system
	Animals accidents
Question 6**:** Please, compare the main risk factors overall, and rank them from (1 - 5). Where: 1 means the heights risk factor, and 5 means the lowest risk.	
	Security & Social (S&S)
	Pipes' Location (PL)
	Health, Safety and Environments (HSE)
	Rules and Regulation (R&R)
	Operational Constraints (OC)
Question 7: Please, write any other risk factor in your opinion that has not been mentioned.	
Section III: Evaluating Risk Mitigations Methods	
Please, rank the following risk protection methods regarding the degree of applications and effectiveness. Question 8: Protection methods usage scale. (Almost certain used, Likely used, Possible used, Unlikely used and Rare used) **(Five-Points Likert scale)** Question 9: Protection methods effectiveness scale. (Extremely effective, Very effective, Moderately effective, Slightly effective and Ineffective) **(Five-Points Likert scale)**	
	Avoid "Insecure-Zones
	Anti-terrorism design
	Avoid the registered risks and threats
	Proper training
	Move to an underground pipeline
	Anti-corrosion such as isolation and cathodic protection
	Protective barriers and perimeter fencing
	Warning signs and marker tape above the pipeline
	Foot and vehicles patrols
	High technology and professional remote monitoring
	Government-public cooperation
	Proper inspection, tests and maintenance
	Question 10 Projects' stages
	Planning & design stage
	Construction stage

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Question 10: Which projects' stage is the most critical stage to mitigate the pipeline's risks. Where 1 means the most critical and 3 is the less critical.	
	A- During the planning and design stage for example, avoid the Hot-Zones and the registered risks and threats; anti-terrorism design; and proper training.
	B- During the construction stage for example, move to an underground pipeline, corrosion protection, protective, warning signs and marker tape above the pipeline.
	C- During the operation stage for example, patrols; high technology and professional remote monitoring; government-public cooperation; and proper inspection and maintenance.
Question 11: Overall, by comparing between the above and under the ground pipelines, which pipeline has the less opportunity of third-party risk disruption?	
	The aboveground pipeline despite it exposed, and it can provide sabotage and thefts opportunities.
	The underground pipeline despite the corrosion, geological, constructions and maintenance risks.
Question 12: Please, write any other risk prevention method in your opinion that has not been mentioned.	
Question 13: Please, if I need additional information, could I contact you? Please provide any contact information if you agree.	

The final draft of the survey had 13 questions divided in three sections as follows. Similar to the pilot-like survey, section I explained an introduction to the survey. The first three questions were asked about the participants' occupation, experience, and degree of education. Section II of the questionnaire survey comprised four questions to analyze the RFs. Question 4 asks about the probability levels of the RFs. Question 5 asks about the severity levels of the RFs. Question 6 asks to rank the RFs by their degree on influence on OGPs. And, question 7 was an open-ended question to add more RFs for the survey by the participants. Section III: had five questions to evaluate the RMMs. Question 8 askes to evaluate the usability of the RMMs. Question 9 askes to evaluate the effectiveness of the RMMs. Question 10 asks to rank the stages of pipelines' projects regarding the priority of mitigating the RFs. Question 11 was about an overall comparison between aboveground and underground pipeline with the subject to RFs. The final question was to collect the participants' contact details.

5. Discussion

Questionnaire surveys have always been used as data collection methods in social researchers and operations strategy researchers. A well-structured questionnaire survey and clear and to the point questions considered proper because, they made the survey easier for the respondents and also allowed the researcher focus on the variables of the survey, which makes the analysis of the survey easier to them. Moreover, it is essential to be aware of the ethical considerations in the survey to protect the privacy of the participants.

Sampling means to select some from a larger group to estimate or generalize the dominance of an unknown chunk of information [20]. The snowball sampling technique was applied for this survey to ensure widespread distribution of the survey [21,22]. This technique works as follow; the survey will initially distribute to some previously identified participants who will be asked to forward it to others until the required number of responses is reached [21].

An online tool was chosen to distribute the survey because it is a quick method of data collection compared to mail and paper survey, easy to manage, less cost and environment friendly [23]As well as, the online survey provides a chance to the participants to cooperate and explain their idea about the via open-ended questions [24]. However, this kind of survey might have a low response rate that results from some disadvantages like computer and website literacy, the targeted population or some of them might not have access to the Internet and web security issues [25].

6. Conclusion

This paper describes an aspect of developing a questionnaire survey as part of ongoing research about mitigating the RFs in OGPs projects. The survey will use an online tool to recruit respondents that have relevant experience with OGPs projects such as planners, designers, consultants, construction workers and operators.

Collecting the required data by using questionnaire surveys could reduce the time and cost of investigations, increase the stakeholders' awareness about their responsibilities regarding OGPs risk management. However, it depends on stakeholders' willingness to cooperate with the authors, which is one of this method's main advantages. Collecting the required information from various and trusted sources such as previous studies and stakeholders could provide additional understanding and knowledge about OGPs' safety. Also, the collected data could provide reliable and valid data about mitigating RFs in OGPs projects to analyze the RFs more accurately. Moreover, it helps to identify the positive and negative recommendations about RMMs in a way that ensure the planes and strategies for pipelines' safety.

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The impact of view-restriction: a Delphi case study from Budapest

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Abstract

Based on the international literature, the effect of an existing panoramic view on the Market Value of properties is positive and significant. This value-adding factor varies by location and by type of view. In Central Europe, no such evaluation study has been elaborated until now.
New building construction may restrict the existing panorama; this is the other side of the same phenomenon. View restriction may result in stigmatization, a negative effect on the property. There are two major methodologies to observe the effect – Revealed Preference Method (RPM) and Stated Preference Method (SPM). One SPM approach is Contingent Valuation (CV), wherein well-informed stakeholders give their opinion about the impact caused by the investigated effect. The CV methodology – using the Delphi approach – was employed to observe the Market Value decrease in the cases of several restricted panorama situations in Budapest. Based on the research, this effect in Budapest is in line with published western results. The result of the study can be used to support real estate developers and architects in their development decisions.

Keywords: Market Value, Panorama, Stigmatized Property, Delphi Method

1. Introduction

In the international literature, the value-changing effect of a panorama in real estate has been studied extensively and in many different ways. Various studies have provided estimates for the added value of panoramas, with significant standard deviation [1]. However, in certain regions and cases, experts' findings converge more and more. We may conclude that a strong professional consensus has emerged regarding individual environments and panorama types. It should also be noted that the literature agrees that the existence of a panorama in the case of a residential property is a significant value-increasing factor [2]. However, to the best of the author's knowledge, the studies carried out so far have not yet covered the Central European region.

The virtual counterpart of the panorama's value-increasing effect is the reduction in value that results from the restriction of the view. We assume that the increase in value caused by the existence of a panorama and the decrease in value that results from its restriction show a close correlation. The effect of view-restriction can be studied and quantified based on the effect of the existence of a panorama and vice versa: the decrease in value resulting from a construction in front of the building can provide an estimate for the value of a panorama.

The possibility or factuality of view-restriction is a sort of encumbrance on a real property. The definition of stigmatised real estate is the following: *"Stigmatised real estate is a property that is marked by an external negative impact. The external influence may reduce the value of the real estate through a specific multilayer filter"* [3]. Given that the value of a view is generated as described in the definition, i.e. through a multilayer social, cultural and communications filter on individual real estate markets, such events of view-restriction fall within the scope of stigmatised real property.

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In the literature, the methods typically used for estimating decreases in the value of stigmatised real property can be divided into two groups: Revealed Preference Methods (RPM) and Stated Preference Methods (SPM). The majority of international studies follow RPM, applying one of its frequently used analytical methods, the generation of a hedonic model. However, in data-poor areas, several authors use SPM, particularly one of its branches, the Contingent Valuation (CV) method.

That said, the hypothesis in this article is that the extent of the decrease in value that results from view-restriction regarding residential properties situated in Budapest follow the trends that determine the value of panorama, which were described in the literature. To examine the hypothesis, we used the Delphi method, which is part of the CV methodology.

Following these introductory thoughts, the article will present the research in the following structure: first, it provides a review on the findings of the literature, then it describes the methodology and implementation of the examination, and finally, it ends with the analysis of the results and the conclusions.

2. Literature Review

The literature already discussed the value-increasing effect of a view back in the early 1900s [4]. The first hedonic analysis that has provided an actual value was published by Brown [5] in 1977, when he studied the value-increasing effect of waterfronts. He has made the important conclusion that the value of a real property decreases as the distance from the waterfront increases; three quarters of the value-increase caused by a waterfront location is already lost 100 metres (300 feet) away from the waterfront. In 1994, Rodriguez and Sirmans [6] studied the market for detached houses in Virginia (USA), and concluded, based on 194 observations, that the existence of a panorama leads to an 8% increase in value. This finding has been frequently cited ever since. The type of panorama had not been specified in early studies; Benson et al [7] were the first to do so in 1998. Benson et al analysed 11 years of data, obtaining variables from an official valuation database. Since this database did not contain any data on the view, they visited the entire sample of 5,000 and personally rated the view of each property, i.e. how full or restricted the panorama is. The time factor was treated as an annual, so-called “dummy” variable in the model. The distance from the waterfront was also taken into account as an additional variable. This study also confirmed that the view is a significantly value-increasing factor, as well as the fact that the closer the property is to the waterfront, the higher the value-increasing effect gets. According to their analysis, the value-increasing effect of a view of the ocean is 60%, that of a “nice view” is 30.8%, that of a “good view” is 29.4%, while that of a partial view to the ocean is 8.2%. According to a study carried out in Minnesota (USA) based on nearly 5,000 observations, the value-increasing effect of a waterfront panorama regarding a residential property is 10% [8].

Market players with different cultural backgrounds provide differing estimates in various geographical environments. In Hong Kong, where high-rise buildings are typical, a panorama of the ocean (based on 1474 observations) only increased the value by 2.97%, based on the hedonic method; moreover, a view of mountains even had a 6.7% value-reducing effect [9]. A study carried out in South Africa (230 observations) concluded that the value-increasing effect is 18% [10]. However, in Geneva, Switzerland, a panorama of Lake Geneva can be as high as 57% [11]; interestingly, if this view also includes the famous fountain, the Jet d’Eau, the value further increases by 3.6%. Fleischer studied hotels in the Mediterranean, as well as their pricing, in 2011 [12]. Based on the hedonic analysis of the prices of 2819 hotel rooms, the author found that a view of the sea leads to a 10% increase in the room price, regardless of seasons and regions. However, a partial view of the sea (e.g. if the panorama can only be seen from a part of the balcony) does not change the room’s price. Staying within the region, according to a study carried out using the CV method, the view of the Acropolis in Athens has a value-increasing effect of 56% [13].

Authors have tried to differentiate types of panoramas in various manners. Previous studies categorised different panoramas based on their degrees or the extent of the obstruction, and represented them in the model with a “dummy” variable [1, 2, 5, 6, 7, 8, 9]. Another solution is to segment the view and describe it based on its composition [14]. In the most recent literature, authors focus on determining and analysing the field of view. Certain authors consider the view angle as a hedonic variable [15, 16]. Fung et al [15] created a simplified model. The authors introduced the Shadow Mask variable (SMK). This – parallel to the view – measures the view of the open sky. In their studies, they show that three view angles (40, 90 and 140 degrees) give a good approximation to the full value-changing effect of the shadow mask. According to an article of Mothorpe and Wyman from 2017 [16], in the event of non-waterfront parcels, a 1% increase in field of view results in a 0.42% percent value-increase, while in the event of directly waterfront land, this value is 3.85%. With the methodology of computer assisted aerial mapping, LIDAR, the automatic examination of the field of view is more and more frequent. As part of this, the size of visible water surface [8, 11, 17, 18] and green surface [18, 19], as well as the view of open space [18] are rated with the use of automatically interconnected regional (GIS) and aerial (LIDAR) databases.

As we can see, in the research of the panorama's value-increasing effect, the application of methods for analysing stigmatised property, particularly the hedonic method, is dominant [1]. The application of the "Spatial Durbin" model, which filters out spatial interaction and is used in the most recent studies, can be considered an improvement of the hedonic model. [20, 21] However, analysts also use methods related to the CV methodology, which is based on fuzzy logic [14] or the Delphi model [13].

In Central Europe, the number of scientific studies carried out with regard to stigmatised real estate is negligible. Some research has already been carried out using the hedonic model on detecting the stigmatising effect of the Budapest Ferenc Liszt International Airport [22] and the differences in the values of historical buildings [23]. According to the literature explored by the author, no research has been carried out in this region regarding the value-changing effect of the panorama yet.

3. The methodology of the examination

In a data-poor environment, the evaluation of stigmatised properties can be carried out with the CV method [24]. For the purpose of this study, the Delphi methodology has been selected within the CV method. The Delphi methodology is based on expert opinions that are brought closer together in the course of a joint learning process in order to provide more and more efficient and precise answers [25, 26].

This study followed the standard Delphi method. The expert panel consisted of 20 senior valuers, who are all well-informed regarding the real estate market in Budapest. The panel established its expert opinion as part of the Valuation Knowledge Management Programme of Grant Thornton, an international consulting company, during an all-day event on 31 January 2018. The panelists were previously informed on the Work Programme, which started with an initial opinion survey. The first round of opinions was not presented, instead, the experts listened to lectures on the methods for evaluating the effect of view-restriction, as well as the international literature on the value-changing effect of a panorama. After the lectures, the second query took place, after which the members of the panel learned about the anonymised, aggregated results of the first and second queries. Their interpretation was followed by the third query, then the joint acknowledgment and acceptance of its results.

The panel consisted of 13 male and 7 female experts. The panel members' average age was 51 years and their average experience as valuation experts was 18 years. All panelists had personal experience in the issue of view-restriction; those present have previously provided independent expert opinions in 46 such cases altogether.

The query, in addition to the registration of personal data, consisted of two main parts in all three rounds: first, the participants had to rate different panoramas, then estimate the value-decreasing effect of an establishment that partially or fully obstructs the panorama.

The views intended to represent the real estate market environment in Budapest were the following:

- full view of Budapest with a panorama of the city and the Danube (Image A)
- a rural panorama of hills (Image B);
- a view of houses and roofs typical to densely built-up areas in Budapest (Image C);
- a view of blocks of flats, which defines a significant proportion of the built environment in Budapest (Image D); and
- the direct view of an ongoing construction.

In each case, the question asked concerned the view from the living room of a flat with a floor space of 100 square metres, situated in one of the mountainous areas of Buda. The first figure shows the studied panoramas that have been presented.

Fig. 1. (a) full Budapest panorama; (b) hilly landscape; (c) roof-view; (d) block-buildings.

In the event of the first question, the experts' task was to determine a favourability index for each view on a scale of 1 to 100, where 100 represents the maximum favourability index and 1 represents the minimum favourability index. Of the views, the fifth one, which directly showed a construction, was rejected by most panelists, valuating it to be really unfavourable, as an average of 21 on the scale of 1 to 100. For this reason, this view was excluded from the rest of the study.

The second group of questions presented three situations of view-restriction for each of the four views:

- partial view-restriction due to the installation of a mobile phone tower;
- full view-restriction due to the installation of a mobile phone tower and
- partial view-restriction due to a construction in front of the building (ongoing construction).

The second figure presents the reviewed situations regarding case (a), the full view of Budapest. The same images were shown regarding all four views.

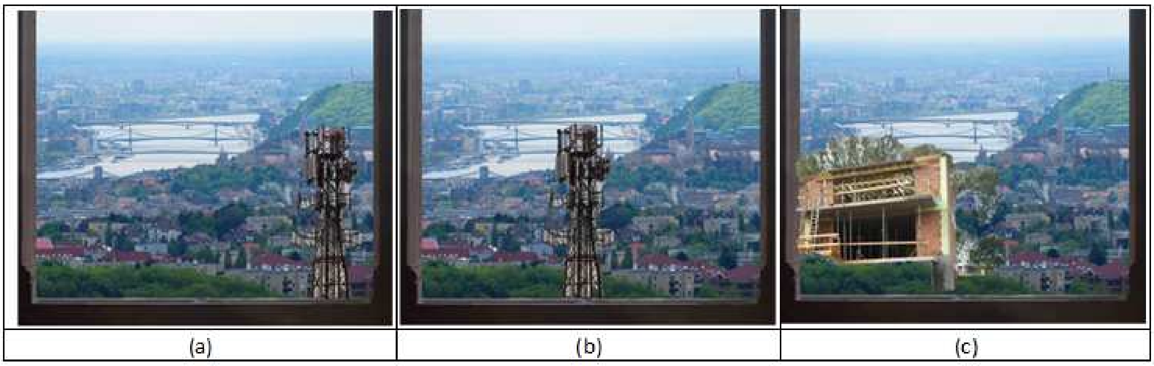

Fig. 2. (a) partial view restriction; (b) full view restriction; (c) partial restriction with on-going construction.

The task of the experts in the case of the second group of questions was to determine the value of the fictional property with regard to the unobstructed (full) panorama for each situation of view-restriction. I.e. if the value of the property is 100 units with a full panorama, the panelists had to determine how many units the value of the property would lose in the event of the view-restriction.

After the third query, the participants did not wish to modify their opinions anymore. Therefore, the unanimous expert consensus required by the Delphi methodology had been established.

4. Empirical results

The results of the answers to the first question regarding the favourability index are specified in Table 1.

Table 1. The statistical indicators of the favourability indices

	1. round			2. round			3. round		
	Average	Median	Std. Dev.	Average	Median	Std. Dev.	Average	Median	Std. Dev.
Full Budapest	80.25	80	13.98	89.75	90	11.36	92.25	97.5	10.45
Hilly view	71.25	70	14.73	84.75	80	11.25	86.00	85	11.42
Roof-view	42.75	40	24.20	58.25	60	14.26	67.75	70	12.19
Block-buildings	26.80	22.5	16.31	44.55	50	19.87	52.30	50	22.68
Construction	4.55	1	8.68	9.55	1	12.27	21.85	15	23.52

The third figure shows well that in the event of each examined view, the favourability index increased in each round. In the event of the first three views, the decrease in the answers' standard deviation confirms the establishment of an expert consensus. However, the favourability indices of blocks of flats and constructions shows a higher and higher standard deviation: the experts participating in the panel had larger and larger differences of opinion regarding these views.

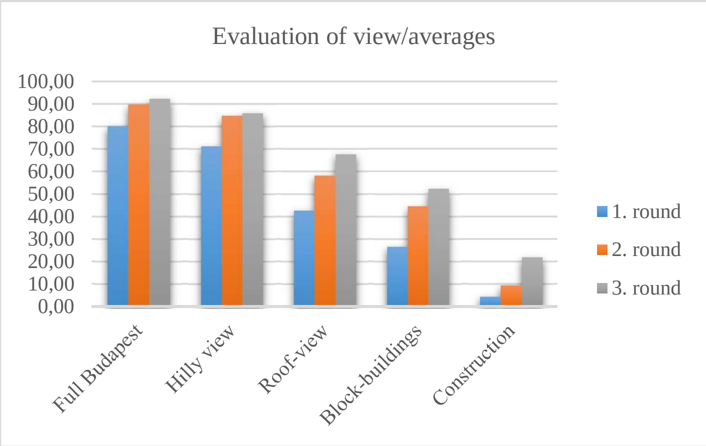

Fig. 3. The averages of the favourability indices

The statistical features of the answers to the second group of questions are specified in Table 2.

Table 2. The statistical indices of the valuations

		1. round			2. round			3. round		
		Average	Median	Std. Dev.	Average	Median	Std. Dev.	Average	Median	Std. Dev.
Full Budapest										
	Partial	76.00	80	21.69	77.95	80	13.50	87.70	90	7.38
	Partial w/const.	64.75	70	20.24	66.90	65	18.54	81.75	85	9.22
	Full	54.80	62.5	24.44	58.00	60	22.62	76.15	80	10.16
Hilly view										
	Partial	73.00	75	17.28	76.35	80	18.17	87.05	87.5	6.43
	Partial w/const.	58.25	60	25.23	62.75	70	24.40	81.75	82.5	7.12
	Full	50.80	50	26.55	54.75	55	25.14	76.40	75	9.91
Roof-view										
	Partial	79.00	90	22.42	72.95	80	26.21	89.05	95	10.39
	Partial w/const.	72.90	87.5	26.68	68.85	80	29.89	85.60	90	12.70
	Full	65.25	77.5	26.64	61.70	65	27.78	82.90	90	11.53

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		1. round			2. round			3. round		
		Average	Median	Std. Dev.	Average	Median	Std. Dev.	Average	Median	Std. Dev.
Block-buildings										
	Partial	76.25	87.5	26.24	67.70	80	32.13	87.10	95	16.10
	Partial w/const.	70.40	82.5	30.55	65.45	80	34.56	84.95	92	19.01
	Full	61.00	77.5	29.50	56.70	70	32.99	81.10	90	17.48

In the table, the standard deviation data related to the answers clearly show that the members of the panel converged towards an expert consensus in each case. In the event of all views, as the examination progressed, panelists gave higher and higher values, i.e. the initial extreme opinions softened in the course of the collaboration.

We examined the correlations between the extent of expert experience and the solidity of their opinions in order to support the results of our research. Based on the number of years in operation and expert opinions established (the latter weighted by 0.2), we assigned an experience indicator to each expert, and compared them to the solidity of their answers to individual questions. The regressive relationship set up this way showed a weak correlation (R=0.590; R^2=0.348).

5. Discussion and Conclusion

Of the results obtained in the study, the findings of the third round made by consensus should be further analysed. The fictional values provided by the experts can be translated to a decrease in value of individual view-restriction cases defined as a percentage; these values are shown in Figure 4.

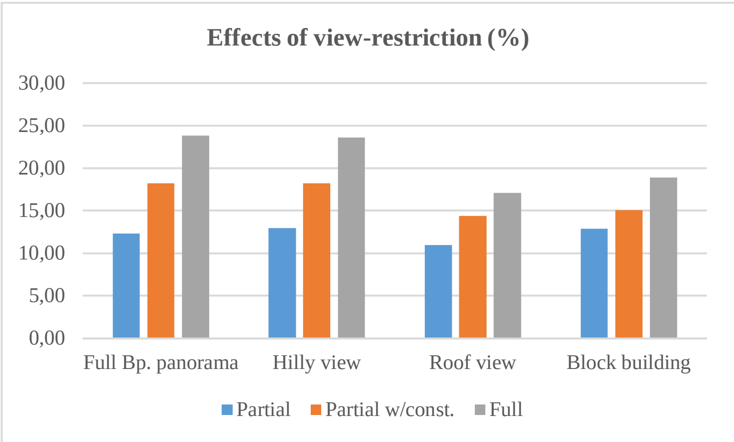

Fig. 4. The averages of the decreases in value

Our initial expectation, that a view with a lower favourability index would entail a smaller decrease in value only proved to be partially true based on the answers.

The value-reducing effect of the partial view-restriction caused by the mobile phone tower is between 10.95 and 12.85 per cent; this technically unanimous opinion is independent of the favourability index of the view that the owner of the property loses. In the event of views with high favourability indices, marked A and B, the effect of full view-restriction were estimated by experts to be higher (plus 11.55 and plus 10.65 per cent), while in the cases of views with lower favourability indices, marked C and D, the difference is smaller (6.15 and 6.00 per cent). Therefore, in this latter event, the fact of the obstruction weighs the same as in the event of views with high favourability indices, while the manner of obstruction (how much the view is impaired) has a smaller significance. Regarding the view angle, however, the previously cited assumption of the literature [15, 16] that the value-reducing effect of view-restriction would be proportionate to the view angle of the obstructed view, was not confirmed: in all three cases examined, the angle of view is practically the same (from the right side, the center and the left side), however, the decreases in value differ significantly.

The presumed significant value-reducing effect of ongoing construction is expected to decline over time [27], particularly when the building is finished and the negative effects of the stigma's first appearance are not attached to the construction anymore. We may assume that in this case the value-reduction caused by the view-restriction of the building will not be greater then the partial decrease in value caused by the mobile tower, i.e. the same decrease in value can be expected from both the first and the second examined cases.

The hypothesis outlined in the introduction, according to which the extent of the decrease in value that results from view-restriction regarding residential properties situated in Budapest follows the trends described in the literature that determine the value of panorama, was confirmed. In the event of views in Budapest, the largest decrease in value is 23.85%, which is related to the restriction of the panorama rated to be the most beautiful (full view of Budapest). This value corresponds to the international literature cited, as well as the 11-13% value of the partial view-restriction established by the expert panel. However, the study results presumably include an additional element of stigma as well, since the negative social and community sentiments related to view-restriction are larger than the added value of the existing panorama. Therefore, the existence of a panorama may be assumed to have a lower value-increasing effect than the percentage determined by the expert panel in relation to Budapest.

The study is doubly limited due to its location. First of all, since the extent of the decrease in value caused by the view-restriction, according to the conclusions in the literature, is geographically bound, the results can primarily be used in Budapest. Second, since there are no databases available that could be suitable to apply the RPM methods, particularly the hedonic procedure, the backtesting of expert opinions with factual data is not yet possible. However, these research findings and the value-reduction values obtained may be useful for the preparation of real property development, the planning of building orientation with regard to the view, as well as the settlement of disputes regarding view-restriction. The Delphi method described here can also be easily implemented in other Central European locations, thereby also creating the possibility of comparing the value-changing effects of views regarding different locations.

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The influence of historical conditions on time and cost of construction project

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Abstract

Conducting construction works in a building or in an area entered in the historic register is associated with the contracting authority's risk of incurring higher than planned costs of works, as well as delays in their implementation. In many cases, these deviations are completely independent of contracting authority and contractor. The aim of this article is to indicate the reasons for cost and time changes in the construction project, which is influenced by the historical conditions of the building site's location. In practice, the detailed considerations presented in the article may contribute to increasing the efficiency of spending public funds in the implementation of construction projects of a specific nature.
Based on the selected example - reconstruction of the Old Pharmacy building located in the historic part of the old city of Gdańsk, the authors analyze and classify factors affecting the cost and time of construction works taking into account the historical conditions of the location of the facility.

Keywords: construction project; contracting authority; historical conditions; location; time and cost factors;

1. Introduction

The correct determination of the cost and completion date of the construction project is an essential element in making an investment decision and forecasting the economic consequences of a project. This issue is important from the public purchaser point of view, but also the contractor of the construction works preparing the tender. In practice, a given construction investment can be attributed to three basic amount [1-3]:

- the value of construction works estimated by the ordering party in the investor's cost estimate at the stage of project preparation,
- the amount entered into the content of the construction contract, i.e. proposed by the contractor selected on the basis of the analysis of the tenders submitted for the tender procedure,
- the actual value of the investment determined after its completion, including (in the replacement cost estimate, implemented or offer cost estimates for the additional scope of works) the value of supplementary and additional works.

In the case of public procurers, another type of amount may be mentioned, which value is given to the public immediately before opening tenders, and this is the amount the contracting authority intends to spend to finance the contract, most often resulting from a budget statute or financial plan. The amount mentioned above are often

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significantly different from each other. Its change usually entails discrepancies in the planned time of investment implementation.

The analysis of the literature on the subject indicates that investments carried out in the areas of historical cities have so far not been subject to detailed research in the field of factors that give rise to cost and time overruns. For this reason, the purpose of this article is to indicate the reasons and scope of changes in the cost and deadline for the building construction, taking into account the historical conditions of its location. Based on a selected example - reconstruction of the Old Pharmacy building, located in the historic part of the Old City of Gdańsk, the authors analyze and classify factors affecting the cost and time of construction works completion.

2. Exceeding the cost and time of construction project implementation – the literature review

The subject addressed by authors in practice is a very important issue - in many countries extensive research is carried out regarding the time and costs of construction completion, including research of the following authors [4-8]. The literature on the subject emphasizes that long-term and large-scale projects are much more likely sensitive in terms of time and increased costs [3,9]. The macroeconomic conditions of the country in which the project is implemented are also significant [10]. Detailed, often individual factors, negatively affecting the time and cost of the project implementation depend primarily on the scale and nature of the investment, its location, environmental conditions, the adopted technology and organization of works, construction management, as well as the specificity and importance of the project [11,10]. In the literature can be found numerous examples of research that concern large public construction projects (including the so-called mega projects, most often concerning infrastructure investments), and smaller ones, constituting a collection of several smaller-scale projects, together forming a large project (e.g. housing construction [7]). Factors giving rise to cost and time discrepancies in the areas of historical cities, which are of authors' interest, according to the literature have so far not been subject to detailed research.

2.1. Cost overruns in construction projects

Many construction projects are facing serious cost overruns due to various reasons [12]. According to the research carried out by Moms and Hough, the vast majority (63%) of 1778 building projects financed by the World Bank in 1974-1988 exceeded their budget [9]. This problem is deepened in the case of large infrastructure projects (railway and road investments). The conducted research indicates an increase in costs at the level of 50% - 100% and even higher [13]. The data analyzed in the analysis [9], carried out twenties to nineties, refer to investments carried out in various parts of the world, covering 5 continents and 20 countries. It can be concluded that the increase in the costs of construction investments is a global phenomenon. The situation is even more serious in developing countries, where corruption has a significant impact on the actual costs and accounts for 10-30% of the construction contract value [8,14]. The research also indicates that referring to the possible form of remuneration for the construction project, the largest increase in costs is observed in contracts with a flat-rate settlement, slightly smaller with a monthly settlement, and the smallest in the case of the refund agreements [3].

The classification (ranking) of the factors most frequently mentioned in the subject literature, constituting the reason for the increase in the cost of a construction investment, is presented in Table 1.

Table 1. The ranking of the factors most frequently mentioned in the literature as the reason for cost overrun in construction projects (in order of the most to the least often mentioned factor).

Ranking position	Factor
1.	Poor estimation and financial planning /cost underestimation
2.	Project complexity and duration - changes in requirements
3.	External macroeconomic factors (i.e. the cost increase: labour, materials, equipment)
4.	Poor management, monitoring and financial control
5.	Poor workforce skills and experience affecting quality of construction works
6.	Poor material planning/ change orders
7.	(Short) time to deliver the project / underestimate project duration
8.	Poor design and implementation
9.	Adverse weather conditions
10.	Bureaucratic indecisiveness and the lack of coordination between enterprises

source: own study based on [2,3,7-10,12]

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2.2. Time overruns in construction projects

As in the case of cost overruns, a delay in the execution of construction works is a frequent phenomenon. According to the literature of the subject [9,11,15], about 35% - 65% of the planned activities, are not carried out according to the schedule [11]. Other studies [9] indicate that about 25% - 30% of planned activities are delayed.

The classification (ranking) of the factors most frequently mentioned in the subject literature, constituting the reason for extending the duration of a construction investment, is presented in Table 2.

Table 2. The ranking of the factors most frequently mentioned in the literature as the reason for time overrun in construction projects (in order of the most to the least often mentioned factor).

Ranking position	Factor
1.	Poor quality of the management and supervision, lack of communication
2.	Mistakes and inconsistiencies in the design documentation
3.	Poor workforce skills and experience affecting quality of construction works
4.	Ineffective planning (including the development of schedules)
5.	Poor material planning/ change orders
6.	Adverse weather conditions
7.	Investor's difficulties in obtaining funds to finance the investment
8.	Difficulties in obtaining the necessary permits to implement the works
9.	Unrealistic (too short) period of project implementation
10.	Insufficient necessary equipment at the construction site

source: own study based on [4-6,9-11]

2.3. The specificity of construction projects carried out in historical areas

The literature review allowed to identify factors that in the opinion of many researchers, have a significant impact on the increase of costs and duration of construction investments. Most of the mentioned studies refer to the scale of implemented investments, not their specificity [16,17,18].

In the opinion of the authors, there are no examples of smaller projects, which due to their special and unique character, are also exposed to a large increase in costs and extending the time of their implementation. Such undertakings include investments carried out in the areas of historical cities.

It is pointed out that maintenance projects related to renovation, reconstruction, modernization, change of use, additionally carried out in hardly predictable conditions, usually experience the most serious delays and, as a consequence, increase in costs [9]. Investments in historical areas are often located in city centers - this is an additional cause of disruptions. In this case, a reliable development of the construction schedule is a particular difficulty and requires a precise analysis of the conditions under which the works to be carried out [19].

The article attempts to classify and define the scope of impact, on the cost and timing of construction works, the main causes of disturbances. An unusual feature of the presented approach is the inclusion in the factors analysis resulting from the historical conditions of the object location.

3. The analysis of time and cost discrepancies - case study

3.1. The subject of the analysis

The construction works being the subject of this analysis were carried out from December 2016 to March 2018 as a part of the project entitled *"The improvement of the condition of the historic building of the Old Pharmacy from the 17th century, along with the Gateway Passage and the defensive walls of the Main Town in Gdańsk, by giving new cultural functions"*. The project is implemented, among others from the resources of the Regional Operational Program for the Pomorskie Voivodeship under measure 8.3 Material and intangible cultural heritage of the Pomorskie ROP for 2014-2020. The beneficiary of the funds and the implementer of the investment is the local government cultural institution - Wybrzeże Theater. The aim of the investment is to increase the tourist attractiveness of the Main Town in Gdansk by using the potential of historic buildings. The scope of the project includes the revitalization and reconstruction of the historic facilities of the Wybrzeże Theater in Gdańsk, including 17th-century Old Pharmacy and Gateway Passage. The goal is constructing a new stage with a rehearsal room and an observation deck in the Gateway Passage and a foyer in the Old Pharmacy. The project is part of a wide range of activities including the modernization of the Malarnia scene, the construction of a new Old Pharmacy scene, the modernization of the Large Stage and Teatralna Street, the construction of a glass connector between the buildings. The completion of construction works, with the exception of the stage mechanics in the main building, is planned for 2021. Its scope of activities includes:

- Main building
- Malarnia stage
- Old Pharmacy and Gateway Passage
- Underground technical building
- Modernization of the courtyard
- Teatralna Street
- Theater surroundings (Targ Węglowy, Parking).

In 2015, at the request of the ordering party - Wybrzeże Theatre, the project and cost documentation was prepared for the entire project. In 2017, for some of the objects it was updated. The value of the project was estimated at approx. 90 million PLN. According to the design, all objects are interconnected, including through two ground links and one underground, running under Teatralna St. The implementation of the project depends primarily on the financial resources possessed and acquired by the Ordering Party, and the stage of implementation is to ensure the continuous operation of the unit whose main statutory task is cultural activity.

3.2. Historical conditions of the object location

The building of the Old Pharmacy and the brick fence of the former courtyard between the Old Pharmacy and the Great Armory, which was adapted as the external wall of the new stage building with the auditorium (the project was planned in the place of the former Gateway Passage), are objects entered into the Monuments Register of the Pomeranian Voivodship. The building of the Old Pharmacy was built in 1636 on a quadrangular plan as a detached building. Historical documents show that it was built on the site of a tower built in the middle of the XIV century and demolished in 1636. In 1952, the Gothic foundations of the tower on the rectangular plan were uncovered, made of brick of the Wendish system. Research shows that the Old Pharmacy building was located on a fragment of one of the towers, located between Słomiana Towel and Szeroka Towel and Szeroka Gate [20].

The reconstruction of the Old Pharmacy building and the construction of a new stage in the former Gate Passage were preceded by conservation works on the front façade of the Old Pharmacy building, high and low wall conservation, demolition works and excavations in the former Gateway Passage (including archaeological research), as well as the construction of an underground technical building.

It is important that works are carried out at historic buildings with cultural values in the city of Gdańsk, with a range of fortifications from the XVII century and a monument of history.

The scope of the contract is divided into 5 stages:

- Stage 1 - Old Pharmacy
- Stage 2 - Gateway Transition, I.1-I.5 axes
- Stage 3 - Gateway Transition, I.5-I.9 axes
- Stage 4 – Connector
- Stage 5 - Subscriber transformer station.

The area where the investment is located is characterized by a compact and sensitive to noise and vibrations building - in the immediate vicinity there is an artistic public university, a hotel and a functioning theater.

3.3. Reasons for cost and deadline discrepancies

The analyzed case concerns the implementation of the raw state of the new stage and the building of the Old Pharmacy. The estimated value of the implementation of this works scope of the contractual party was set at 3 782 688 net PLN, the completion date was scheduled for June 2017, i.e. after 177 days (26 weeks) from the date of signing the contract. As the part of the demolition works, the demolition of a transformer station was planned after the transfer of the transformer substation to the underground technical building. The demolition work was planned for March 2017. The demolition works started in August 2017, therefore the transfer of transformers was delayed. During the demolition works, historic foundations were discovered. According to art. 32 para. 1 of the Monuments Protection and Maintenance Act [21], the Ordering Party notified about that fact the Pomeranian Provincial Conservator of Monuments (PWKZ). After the inspection, the PWKZ ordered the suspension of works, protection of relics and archaeological research at the expense of the Ordering Party. A separate PWKZ decision was required to carry out archaeological research, therefore the Ordering Party was obliged to apply to the PWKZ for a permit to conduct research. The application should indicate, the head of the research team, therefore the Ordering Party was obliged to conclude an agreement with an Archaeologist with appropriate qualifications. The task of the Archaeologist was the preparation of the Research Program. From the day of submitting the application for conducting archaeological research, 25 days have passed until the date of obtaining the PWKZ decision. The decision was the basis for the archaeologist to start work. On the basis of the conducted research, in consultation with the author's supervision, technical expertise was drawn up, which showed that the condition of the walls is poor, the foundations have numerous cavities and debris, do not represent historical value, and the low curtain wall between the foundations is contemporary. After completing the archaeological research, the Investor submitted to the PWKZ an application for the issue of a permit for the demolition of the walls, however, PWKZ did not allow the demolition [22]. In the explanatory memorandum to the decision, he pointed out that exposed walls constitute the gothic foundations of the medieval tower, demolished medieval tower in the modern period under the Old Pharmacy, replaced by the building of the Old Pharmacy. PWKZ stated that the condition of the walls allows to read the original function of relicts and reconstruction of the tower's foundation. From the day of the archaeological research to the date of the above decision had passed 27 days. Taking into account the information contained in the PWKZ decision, the discovered relics have a historic value and scientific value (they constitute an original historic substance, whose chronology dates back to the XIV-XV centuries, it is an unique discovery), the investor was forced to adapt discovered relics in the designed space. The contracting authority was also obliged to develop a conservation program and a temporary wall protection project. According to the PWKZ recommendation, in order to protect the relics against possible destruction, the Ordering Party ordered a temporary support of historic foundations in the form of a steel grate. This solution had to be approved by PWKZ. The support of the walls was carried out by the Contractor of basic works for a separate remuneration. After strengthening the walls, the Contractor commenced earthworks in order to obtain the ordinate of the foundation slab. After receiving the construction drawings from the designer, the Contractor resumed work on the construction of the building in I.5-I.9 axes. 125 days had passed since the date of suspending works (4 months and 3 days). This time was devoted to archaeological research, protection and reinforcement of uncovered foundations and introduction of changes to the project documentation. The development of replacement designs was carried out by author's supervision for a separate remuneration. The need to adapt the exposed walls resulted in a number of functional and structural changes in the designed building.

3.3.1. Detailed analysis of cost discrepancies

The value of works, in accordance with the contract concluded by the Ordering party and the Contractor selected for the execution of the basic state, amounted to 2 698 640.00 net PLN (i.e. 3 319 327.20 gross PLN). According to the project's budget (set at the stage of submitting the application for co-financing), 3 152 240.00 net PLN was planned for the task (3 877 255,20 gross PLN). Therefore, the value of contracted works was lower by 1 084 048 net PLN than the estimated value of the order (i.e. by approx. 28%). In table 3 is presented the division of the contract into stages, along with the assumed time of their implementation and values.

Table 3. The planned completion time and values of individual work stages.

No.	Work stage	Planned duration of works [number of days]	Planned implementation period	The net value of works according to Contract [PLN]
1	The Old Pharmacy	177	10.12.2016 - 06.06.2017	824 617,63
2	The Gate Passage I.1-I.5	177	10.12.2016 - 06.06.2017	1 041 512,86
3	The Gate Passage I.5-I.9	77	20.03.2017 - 06.06.2017	401 105,64
4	Connector	66	01.04.2017 - 06.06.2017	124 839,87
5	Transformer station	48	10.02.2017 - 31.03.2017	306 564,00
			TOTAL:	2 698 640,00

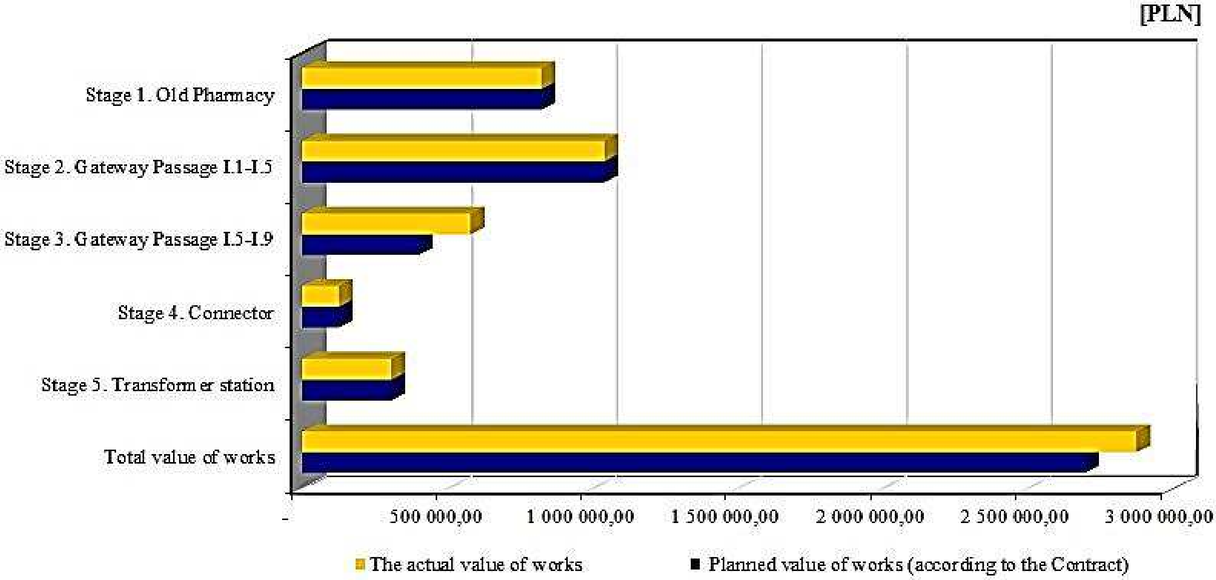

Fig. 1 Planned and actual values of individual work stages.

The scope of work that influenced the increase in the value of Stage 3 is shown in table 4.

Table 4. The list of costs of additional works carried out during the reconstruction of the Old Pharmacy building in Gdańsk.

No.	The scope of additional work	The net value of work [PLN]
1.	The archaeological research	3 724,00
2.	The execution of the replacement project	40 000,00
3.	The implementation of temporary protection of uncovered foundations	92 186,27
4.	The development of the conservation program	5 000,00
5.	The comprehensive restoration of works on foundations	21 500,00
6.	The change of reinforcing steel elements	6 251,67
7.	Change of the location of the heating valves and construction of the technical ceiling	10 199,20
	Total:	178 861,14

As shown in Figure 1, The stage 2 covers the most expensive range of activities and constitutes 39% of the value of the entire Contract. Steps 2 and 3 (Gateway Transition) are interrelated and, in accordance with the Material and Financial Timetable, constitute one stage, with a total value of 1 442 618,50 PLN (split into two separate stages: I.1-I.5 and I. 5-I.9, was made for the purposes of this study).

Stage 3 is only 15% of the value of the Contract, however, there was an unplanned increase in costs. The value of Stage 3 was initially 401 105.64 net PLN, and after taking into account additional work: 579,966.78 net PLN. Its value, compared to the contracted price, increased by 31%, and the value of the entire Contract by 6% and amounted to 2 877 501.14 net PLN.

3.3.2. Detailed analysis of time discrepancies

Figure 2 presents the planned and actual time of completion of individual stages, taking into account unforeseen circumstances causing delays in the execution of construction works. In the analysis of time deviations, the attention should be paid to the stage of administrative and legal activities, which also generate a delay in the implementation of the contract. In the analyzed case, from the moment of suspension of works (in the scope of Gateway Transition, axis I.5-I.9), for their resumption passed 125 days, and during this time decisions and replacement projects were obtained. As indicated in Figure 2, the implementation of Stage 3 lasted 236 days, and therefore the delay in its implementation was influenced more by administrative and legal activities, which accounted for 53% of the delay of Stage 3.

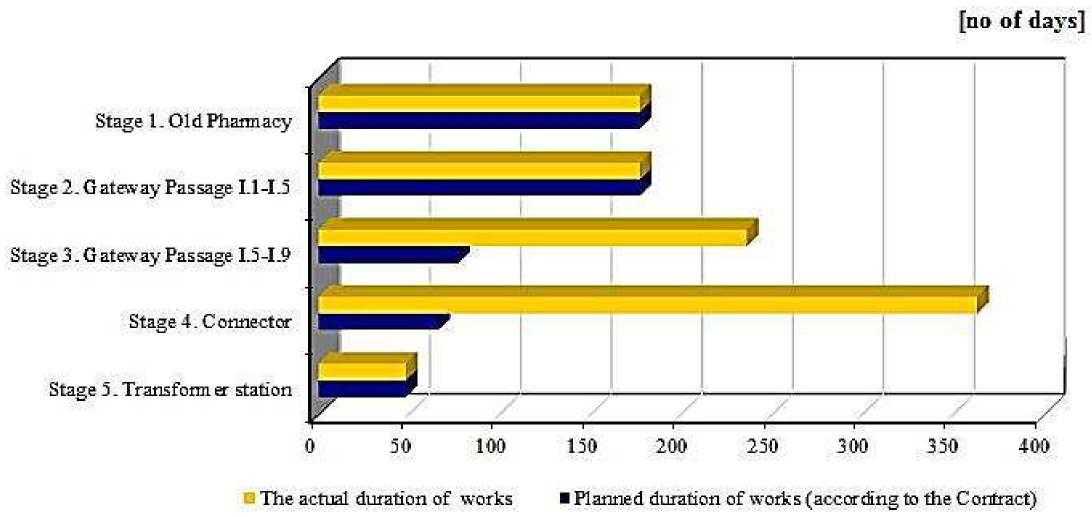

Fig. 2. Planned and actual times for completing particular stages of works.

Table 5. The comparison - planned and actual deadlines for individual stages of works.

No.	Work stage	Planned duration of works (according to the Contact) [number of days]	Planned implementation period	The actual duration of works [number of days]	The actual duration of the performed works
1	The Old Pharmacy	177	10.12.2016 - 06.06.2017	177	10.12.2016 - 06.06.2017
2	The Gate Passage I.1-I.5	177	10.12.2016 - 06.06.2017	177	10.12.2016 - 06.06.2017
3	The Gate Passage I.5-I.9	77	20.03.2017 - 06.06.2017	236	06.08.2017 - 30.03.2018
4	Connector	66	01.04.2017 - 06.06.2017	363	01.04.2017 - 30.03.2018
5	Transformer station	48	10.02.2017 - 31.03.2017	48	10.02.2017 - 31.03.2017

All works, except the Stage 3 (Gateway Passage, I.5-I.9) and Stage 4 (Connector) , were completed in accordance with the original Schedule. In Figure 2 are indicated the Steps in where is a delay in implementation. In the case of Stage 3, it was not possible to start the work within the set deadline.

The implementation of Stage 3 lasted 236 days, i.e. 159 days longer than planned, while the implementation of Stage 4 lasted 363 days, thus the delay was 297 days, as shown in Table 5.

Due to the fact that Steps 3 and 4 were connected with each other, the implementation of Stage 4 was delayed and extended from 66 to 363 days, i.e. by 297 days. It should also be noted that certain stages of works were completed in accordance with the Schedule. However, bearing in mind that the conditions of the Contract did not provide for intermediate dates, but only the final date, it should be recognized that the implementation of the entire project was delayed compared to the originally planned date. The initial planned date of the works was 177 days (26 weeks), however, the real time was 474 days (86 weeks). The delay in the entire Contract was 297 days (42 weeks). The stage 3 implementation time was extended three times (over 300%), while the duration of works for the entire Contract was 267.8% longer than originally planned.

4. Conclusion

The extensive analysis of the literature on the subject and the chosen example justifies the formulation of the following conclusions and statements.

1. The initially planned cost of construction works for the case analyzed in the article was 2 698 640.00 net PLN. In practice, due to the increase in the scope of activities and due to delays, the investment cost increased by 6.6%, i.e. 178 861,14 net PLN. It can be considered that the additional expenditure that had to be incurred by the Ordering party is at the same time the value of the time-cost risk associated with the implementation

of the analyzed investment located in the historical part of the city of Gdańsk. It may also be assumed that in the case of the investment being analyzed, the ordering party has a financial reserve for unforeseen expenses (discrepancy between the amount of co-financing and the signed Contract).

2. An attractive tourist element of the project is the combination of a contemporary theater building with a fragment of a historic building from the 17th century. This resulted in a penetrating effect of the usable space of unique character. However, this led to additional expenses and an increase in the duration of the investment.
3. In practice, a frequent reason that hinders the deadline and economical implementation of large construction projects is the existence of numerous factors of various nature: financial, administrative, legal and organizational. The role of these factors increases in the case of projects carried out in the areas of historical cities. In such cases, it should be paid attention to formal and legal obligations such as opinions and administrative decisions, as well as archaeological research, supervision and conservation inspections, expert opinions, protocols of necessity, applications and letters to the institution co-financing the implementation.
4. The inefficient use of funds (including public, EU structural funds, etc.) is an important and very severe effect of delays and increase in investment costs. In practice, the detailed considerations presented in the article may contribute to increasing the efficiency of spending public funds in the implementation of construction projects of a specific nature.
5. In the case of archaeologically rich areas, the most probable reason for suspending works are historical discoveries. Their occurrence after the commencement of construction and assembly works usually results in the suspension of works in the region of discoveries. It is therefore obvious that in the case of such special locations of construction projects, the possibility of extending the duration of works should be taken into account already at the planning stage of the project. Certainly, prior consideration of the risk of discoveries in the form of a reserve in the areas designated for the planned investment (in the form of extending its time and increasing costs) will contribute to improving the implementation of investments. It also means that, in practice, activities related to archaeological research in areas of potential discoveries should be undertaken in advance – i.e. at the initial stage of investment implementation.

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The Integrated Collaborative Environment and its value to the Procurement Process in the Kingdom of Saudi Arabia

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Abstract

The high level of uncertainty in the delivery of construction projects in the Kingdom of Saudi Arabia, is due to lack of understanding of client requirements and needs. The current collaborative working environment between clients and the contractors needs to be strengthened in order to address this and provide an integrated collaborative environment that is required to improve the procurement processes to add value to the project delivery. This study was undertaken in the lens of interpretivist paradigm. Also, this research presents a comprehensive review of prior studies and suggests a direction for the study in Saudi Arabia. Many studies propose that collaborative work can produce more successful project management of construction projects in many contexts, but this is still a quite under researched topic in Saudi Arabia. The results reveal that the current collaborative way of working is not sufficient to support an effective procurement process. Misunderstanding of this collaborative work working resulted in confusion of applying an integrated collaborative environment in Saudi construction industry. By using integrated collaborative environment both the client and the contractor can enhance those decisions which positively impact the project life cycle. Furthermore, problem solving is important in assisting the understanding of the role of team members' cooperation to achieve the intended goal of the procurement process.

Keywords: clients, collaborative culture, construction, procurement process, saudi construction. Industry.

1.0. Introduction:

The Kingdom of Saudi Arabia (KSA) is one of the most important nations in the Middle East, this is because KSA has the most rapidly growing countries in construction industry. The lack of the concept of a collaborative integrated environment between all the parties are involve in the procurement process, can cause friction between them. Therefore, will becomes a bigger problem when the client is inexperienced in the construction industry, causing him to create confrontations that become more complex to resolve due to his inexperience. Additionally, experienced contractors who do not engage with their clients to setup a collaborative working environment tend to face similar problems. Startlingly, a collaborative approach aims to provide an environment that facilitates built a trust relationship between all parties involved in the life cycle of any project, in a way that benefits the project while providing a win-win solution. However, a lack of integrated collaborative environment between client and contractor often arises from the type of procurement process used as well as putting too much focus on contracts rather than project delivery. This is because procurement is focused on planning and outline rather than processes. Tellingly, procurement can cover the documentation part only while construction is required to cover the implantation aspects. In KSA, the collaborative procurement emphasis and development of long term relationships between client and contractor is not commonly

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practised. Also, many clients are emphases to have the save them right by adding difficult condition to the contractor, this will lead to decrease the trust between them in many ways.

According to Sir John Egan (1998), in his “Rethinking Construction Report” he explained that there are eight parameters of the project in terms improving performance of the project: construction time, construction cost, productivity, profitability, client satisfaction, health, safety and predictability.

Collaborative working can provide a wide number of benefits to the client and contractor, including greater profits, increased market share, economic growth, improved competitiveness between companies and higher chances of survival in the current turbulent global market. These benefits cannot be realised without additional implementation of lean management as a philosophy to support the knowledge of the projects manager, undertaking continuous improvement, and integration between construction processes, effective supply chain management and obtaining customers. In fact, the main benefit of collaborative working is its ability to lower costs as can ensure that, contradictory plans and redundant elements of processes are reformed or eliminated to make them cost-effective. An example of the benefit of collaborative working is given by Professor Partick Danleavy who wrote:

“In England alone we currently have 110 different local library services, and 110 different apparatuses for organising the management of library service, and dozens of different small consortia for book procurement, each involving a small number of libraries. Yet approximately 80 per cent of the stock of public library system is identical country-wide. If we had this setup organised in a different way, could we radially save cost and improve provision at the same time”.

The collaborative approach involves stakeholders; this is because individuals and companies are the main resource to design a successful outcome. This can be achieved by spending time to understand the problem before the strategy is accepted, this is because there is no project without a single problem. A collaborative approach can, together with stakeholders, create a high depth of value added to all parties. This means that collaborative working is more deliberate and allows for everyone to explore and explain the issues before blame each other’s. This helps to fully understand the aim of a collaborative concept which can be put to the right place. On the other hand, procurement in can be complex in some ways of using collaborative working; successful implementation of collaborative working would therefore face some challenges. (Holden, Trott and Wheller, 2011). According to Alofi, Kashiwagi and Kashiwagi, (2016), the largest construction industry market in the Middle East is Saudi Arabia, where the market grew greatly in 2015. However, the industry faced an array of various problems that led to failure in many projects. There is a weakness to understand the project brief which affects the project life cycle in many ways. This is because there is a misunderstanding of construction processes to complete the work and a lack of sharing data/information, namely some companies are protecting this information as a right of them. The government spent millions of US dollars, in an effort to tackle this problem. Researchers have undertaken several studies to measure the size of the problem and highlighted that 70% of Saudi Arabian projects were finished overdue.

In the Kingdom of Saudi Arabia (KSA), the procurement processes used in construction projects do not support the integrated collaborative environment, this is because of historic negative experiences endured by most clients with local and international contractors as well as weaknesses in government procurement policy that fail to penalise those who do not comply with regulations. In Saudi Arabia, the procurement processes used in construction are restricted due to lack of integrated collaborative environment required for further improvements. However, the success of the project depends on the procurement system, that could help improving the Key Performance Indicators (KPIs) of projects, whether having a project management program or working manually it is important to fulfil the key performance indicators. In addition, a cost point as baseline of a budget that related to the client/stakeholder availability, the information is useful and has an important role for any project as it will be followed by a monthly report. Time is a control of the project type, and it is a key to have a clear idea about the project; there is a strategic type of project a stander project. Clearly, a client can explain if his project is strategic or not. Quality is “the ability of a product or service to fully meet the customer’s expectations” (Marr, 2012). In addition, the benchmark is specification it is lead the quality and close out activities record. Furthermore, risk is objective of building up a compelling arrangement of KPIs so as to distinguish pertinent measurements that give valuable bits of knowledge about potential dangers that may affect the accomplishment of the association's objectives. Therefore, the determination and outline of successful KPIs begins with a firm handle of hierarchical goals and risk related occasions that may influence the accomplishment of those objectives. Furthermore, there is a large number of risks that could potentially happen but overall the project’s economic risk is important in order to know the market situation. Progress is a measure of the work that has been completed against what still needs to be done to be done in the remaining time. This is important to know as it can be used to forecast if the project delivery will meet the time and cost targets.

DOI 10.3311/CCC2018-091

The application of integrated collaborative processes between clients and contractors in construction projects in the Kingdom of Saudi Arabia are not carried out in the environment supported by the procurement processes. The total number of work accidents in (KSA) was approximately 69241 accidents in 2014 (Mosly, 2015). The construction industry accounted for 51.35% of these accidents; this percentage when compared to different industries is a large number, but could be due to many reasons; A construction work site - known as a dynamic place with changing environment, usually has a number of workers in same construction are but not all of them they are working on the same activities. Furthermore, construction industry needs to coordinate between the contractor and sub-contractor, otherwise there is a chance for an increased risk of injury. Poor communication between client and contractor may cause can influence to delay in a number of projects in both the private and public sector of the Saudi construction industry. Another factor that can contribute is the lack of maturity of using integrated collaborative environment (Mosly, 2015).

Collaborative working is based on the concept of focusing on customer requirements and it incorporates areas such as, integrated environment management, grassroots environment management, ecosystem management, place based natural management, collaborative planning and collaborative governance (Holden, Trott and Wheller, 2011). If a project is using collaborative working, that then indicates utilisation of collective different ideas and principles from others. Similarly, a huge variety of terms are used to demonstrate collaborative concepts by groups, which may include stakeholders, councils, consensus groups and the community as a whole. Integration between all those aspects achieves the concept of collaborative management and leads to several different types of decision scales and levels. Collaborative working often focuses on finding solutions and implementing them in a way which delivers opportunities to stakeholders.

2.0. *literature review**:***

Despite industry awareness of the benefits of collaborative working, prevailing current culture remains a significant barrier to achieve the approach in actuality. According to Batchelor (2013), in order to improve the ratio of success, the manager must make sure that everyone is working towards the same vision. This will provide the absolute essence of project success that means delivering the objective of project to the people for achievement of their goals. Furthermore, it can maximise the results from risk and value management by continuously assessing the health of project and the most effective strategies for addressing any processes. To ensure the provision of a workplace with an efficient design, a collaborative environment with input from different people is required. It is imperative that a definition of efficiency and effectiveness of the finished article is understood. A business needs to determine the factors required to be in place for determining the right building for their new project or location. A collaborative environment supports delivery of these factors in the property if the design of workplace informed by this principle. Every organisation has its own preferred design for an effective workplace. As businesses typically face limitations on resource, establishing a collaborative approach to project delivery will enhance number, variety and validity of options available for provision of customer needs and eliminate this weakness. Companies understand the importance of how the physical workplace affects their business goal achievement and productivity. Because of this, companies put a lot of thought into improving the design of the workplace. Collaboration is a knowledge defined as the effectiveness of internal and external network (Batchelor, 2013).

2.1. *Collaborative environment:*

Collaborative working can be defined by Barbara Gray as a process through which "parties who see different aspect of a problem can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible" (Margerum, 2011).

Collaborative working has become an established trend of the twenty-first-century thinking. The demand in society to work and think together on situations of critical concern has been suggested as best practice in ever increasing intensity. It is recognised that collaborative working allows transfer of risk from the individual to groups, generating ideas as a community (Montiel-Overall, 2014).

Collaboration needs a strong network, as the most challenging part of its implementation is translating the requirements in the process to achieve the desired result. After defining the path to achievement of results, it will be more straightforward to implement. This will also ensure that the client perceives that the outcome achieves maximum value (Margerum, 2011).

Trust and respect, are necessary for collaboration to be active are deliberate. These features contribute collaborative activities, such as shared planning, shared creation of integrated instruction and shared thinking.
To transport this theory to practice it is noted that "collaboration is a promising mode of human engagement but in order to become more than a passing fad, a theoretical structure and framework are needed to guide individuals and groups toward successful collaboration" –Vera John-Steiner.

Construction projects involve a large number of stakeholders such as owner, contractors, sub-contractors, consultant, designers and suppliers. These stakeholders have to join and work together on the processes and phases of construction. Generally, and traditionally, most of these stakeholders have demotivation to work or join with some other parties - this is because stakeholders are looking to have maximum profit to their own ends only, and agree to some profit for others. The poor performance well-documented in the construction industry to date can be attributed critically to this nature of fragmentation. With the globalised economy, the rapid development of technology, and ever-changing business environment in construction area, this should be addressed. Key initiatives have been proposed for addressing the improvement of performance in the construction industry, such as research of international council for building on "Re-engineering Construction" and the study of lean construction including "Supply Chain Management." Furthermore, following suggestion of Sir John Egan's report (1998) "Rethinking Construction" and Sir Michael Latham's report (1994) "Constructing the Team," it is encouraging to see contractors, consultant, owners, and sub-contractors changing their way of working from traditional relationship to fully integrated collaboration. Nowadays, there is a recognition for collaborative environment working, this is because of the benefit of working together and operate project management. Collaborative working is become perceived as one of most important factors to ensure success in a construction project (Ren, Shen and Xue, 2010).

Collaboration can encourage project aims to be achieved efficiently and effectively, with the right quantities at the right moment, at the right place and at minimum cost when compared with methods of management.
The typical environment of the construction industry is usually characterised as having antagonistic relationships, a lack of actual cooperation over time and separated operation process and complexity.

The impact of culture on the project health is being uncovered as a significant factor that influence the client's and contractor's approach. Ren, Shen and Xue (2010), state that "a culture of a society is its shared value, understanding assumptions and goals learned from earlier generations. It results in common attitude, codes of conduct and expectation that guide behaviour." The culture of an organisation is "a pattern of basic assumption - invented, discovered or developed by given group as it learns to cope with its problems of external adaption and internal integration that has worked well enough to be considered valid and therefore, to be together to new members as correct way to perceive, think and feel in relation to those problems."

Better understanding of cultural factors will help to minimise and control conflict between parties in the construction industry. Social identity theory describes and analyses the framework of cooperative behaviour of the project team based on cultural orientation (Ren, Shen and Xue, 2010). Therefore, a strong organisational culture can increase a company's performance by facilitating effective internal behaviour. By increasing a company's performance result will be add value the procurement processes manly in cost, time and quality.

2.2. *Factors affect the collaborative environment:*

The most significant factor that will affect collaborative working is **communication**. This is because communication is about sharing information, transferring knowledge and integration between all processes (Lock, 2013). One way communication can be hard to implement as it may not take into account key factors which should be considered in the chosen strategy. Two way communications should therefore always be sought when working on a construction project. Although two-way communication coming from different parties and viewpoints is actually the most complex system for management, it brings the most efficient and effective outcomes. It must be remembered that, communication can be effective or ineffective, depending on the characteristics of the communication. It also depends on how the systems of the companies inform the communication with key indicators such as measuring the quality, performance and following the instruction (Huemann, Keegan and Müller, 2016). Use of two-way communication flow from and between different parties is already in place in the construction industry; however, in practicality this is a real challenge because most organisations are looking for their own gain only.

A number of factors which are important to the construction strategy are decided during the process of implementation by the **digital technologies**. Digital technologies are the process part of communication and can be carried out by governmental or non-governmental organisations and can fundamentally affect the decision making for strategy. These decisions can change the possibility for efficiency and effectiveness of the whole life cycle of a project. In a collaborative system, any digital technologies must be selected carefully and involve the right people to take action, rather than give instruction. **Conflict resolution** relates to the formal and informal processes between two or more parties for resolving any clashes in requirements and difference in recommendation (Margerum, 2011). Effective communication will execute conflict resolution to a high level, because it can allow all parties to understand all issues and to achieve the goals as one team. The simple practice of negotiation can form the cornerstone of conflict resolution. It may additionally involve more formal approaches like mediation, facilitation and arbitration. Supervision will be advance process of collaborative working, which starts with the contract and client explanation of the differences and defending the common goals.

The concept of **Consensus Building** refers to integration between individuals and groups, integrated information between them, finding out a mutual content about problems, aims and agrees on strategies for action. Authors in this field feel that this factor should be addressed in the planning stage to reduce impact of feedback further down the line. This approach, along with an effective communication system plus conflict resolution approach ensures client goals are continuously observed and achieved (Margerum, 2011). Furthermore, co-operation factors affect collaborative working, defined as a process between employees to succeed in achievement of common aims. From the implementation view **co-operation** can be the most important approach that can affect collaborative working - this is because cooperation can control the action and implementation aspects of the project strategy (Musau, 2015).

Hence, co-operative procedures are frequently analysed to inform action through contract or plan. The final factor which affects the collaborative environment in the construction industry is **co-ordination**, this point it has a direct impact on the effectiveness of collaborative working. This is because co-ordination is a process where participants are working together. A co-ordinated approach is crucial for implementation of collaborative working, which needs to be based on mutual adjustment and adaptation. Co-ordination becomes even more important when there are more dynamic settings, interdependent implementation action requirements and less clarity regarding issues and goals. A strong network, people and entities to support the work environment would also be desirable (Margerum, 2011).

To sum up, collaboration has become a specific and topical term in the construction industry research and practice. **Communication, digital technologies** and **conflict resolution** are the key aspects affecting the collaborative environment. Furthermore, **Consensus Building** is the main concept of developing process agreements, and action of those agreements may be operated though a **co-ordinated** and **co-operative** approach. Those point are common procedure with Building Information Modelling philosophy.

BIM is a means to facilitate collaborative working because it provides a clear process for flow of information, using a digital model to show the building (Design, 2014). In the United Kingdom (UK), the Government's strategy states that the '…. Government will require fully collaborative 3D BIM (with all project **and asset information, documentation and data being electronic as a minimum** by 2016'. Principally, the main benefit of using BIM is to ensure that convenient information is established in a suitable structure at the right time, so that a strong decision can be taken during the design process. BIM is not about building a 3D model as a tick-box exercise that does not truly add value to the process, it should be used as the major way for the project to be run and set up (Design, 2015).

2.3. *Building Information Modelling (BIM):*

BIM is a procedure which enables collaborative working to allow the project to be built in a form of virtual environment, therefore project parties can generate the maximum profit. This will lead to improvement of the efficiency and effectiveness of the information shared. The integrated environment allows the team to work effectively – in fact, when the problem is identified in the early stages it is easier to potentially solve. AIA defines BIM as 'a shared digital representation found on open standard for interoperability' (Rowlinson, Zhang and Lu, 2013).

Recently, the construction industry has been addressing maximisation of quality with an emphasis on partnership, joint venture and strategic alliances. It has focused attention towards collaborative working between clients and contractors - shifting ideology from imposing and managing commercial pressures to improving and developing the innovation of the project and technologies. In addition, it has attempted to react to a huge demand in internationalisation of the companies and manufacturing. Rahman et al (2014) identified the main factors that will impact the relationship between client and contractor as: competition, risk within business environment, globalisation demand, while businesses as varied as insurance, new technologies and computers are recognising the high demand of collaboration

 DOI 10.3311/CCC2018-091

in order to survive. Rahman et al (2014), also demonstrate that companies are looking for new technologies such as BIM to improve and develop programmes that offer opportunities to utilise an integrated environment between client and contractor. This is because both sides are looking to improve the construction industry. Furthermore, BIM can allow the contractor to contribute to the BIM model, by adding the updates and progress, confirm the as-built construction of the project and specifying any change that can be implemented in the construction process. From the client's perspective, they will develop this programme and monitor the contractor working throughout the whole process. This feature establishes a strong vision for the client because "with BIM, we are putting information at the heart of the project." In fact, this is what the client wants - the real information and check on performance of the contractor (Allison, 2015).

The importance of BIM in the organisation is that it is 'efficient' as a process and 'effective' in the delivery of projects. The construction business is known for delivering projects late and over budget with the subsequent facility frequently not exactly functioning as expected. Implementation of a BIM approach can bring consistency to a project, not simply around cost performance but rather operation as well. BIM can also help to save costs and carbon emissions by removing inefficient procedures and settling on more educated choices at the opportune time.

2.4. Procurement process in Saudi Arabia:

The procurement system in Saudi Arabia operates under the guidance Ministry of Finance regulations. The Ministry of Finance published in March 1977 and issued by Royal Decree NO.M/14, setting out the procurement system to be followed in K.S.A. In September 2006, Royal Decree NO.58 M was issued, detailing minor changes to the system. The procurement system in Saudi Arabia outlines three possible routes: direct purchases, specific purchases and public procurement competitions.

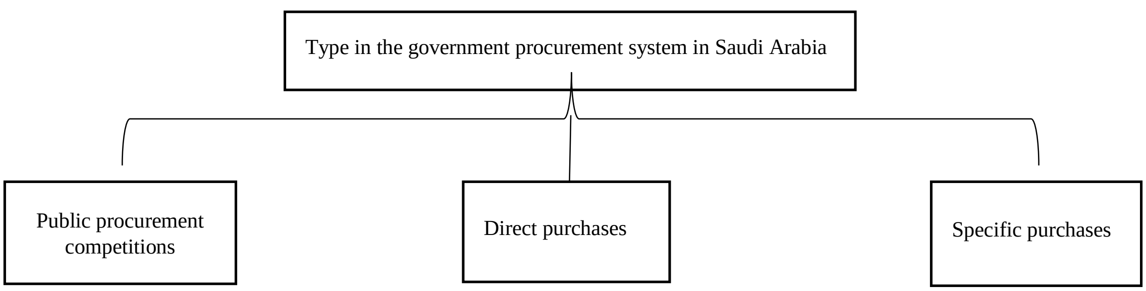
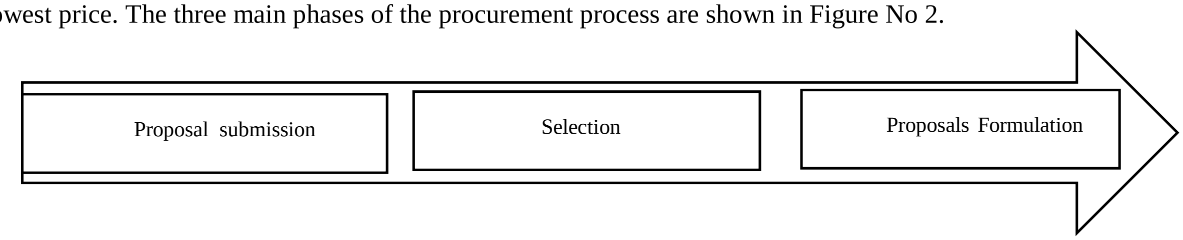


Figure 1: Different Types in the Government Procurement System in Saudi Arabia (Ministry of Finance 2006).

Differing processes are implemented in each type of procurement. The bulk of purchases are executed through the route of public procurement competitions. Therefore, in this type of procurement processes there is a huge number of clashes in many ways during the procurement stages, so will affect the sustainability of any life project cycle.

2.5. Procurement under public procurement competitions:

Projects under public procurement competitions are initiated with the proposal submission phase. Advertisement and issue to all competitors the date of the pre-bid meeting shows the deadline for submitting bids, and the location of where bids will be opened. In this category of procurement, the only criteria for determining the winning bid are the lowest price. The three main phases of the procurement process are shown in Figure No 2.



Based on process and theory of the essential purposes of collaborative environment and procurement processes are for improving productivity, reducing the cost and increasing the performance of the construction industry. Future *business will be able to organise and manage the weaknesses within the construction area. Furthermore, to build an environment under the umbrella of an integrated process and implementation can improve the quality and reduce the cost at the right time. Therefore, by using collaborative environment between the client and contractor will minimise any clashes during the working time between them*

3.0. methodologies:

3.1. Research Methods:

Research methods are, ''the techniques or procedures used to gather and analyse data related to some research question or hypothesis'' (Crotty, 1998:3). According to Walliman (2011) research methods contains two steps of data collection methods and data analysis techniques. The data collection methods adopted was semi-structured interview and participant observation while the Nvivo 10 software was used to analyse the interviews.

3.2. Data collection methods:

The data collection method which was employed in this study is semi-structured interviews and participant observation. According to Bryman and Bell (2011:205) semi-structured interviews refers to ''a context in which the interviewer has a series of questions that are in the general form of the interview schedule but is able to vary the sequence of questions''. Also, according to McLeod, S. A. (2015) participant observation refers to, ''the researcher joins in and becomes part of the group they are studying to get a deeper insight into their lives''. The semi-structured interviews and participant observation allow participants to interact and elaborate the topics than leaving the researcher determining the contents and responses (Barbour, 2014). In the semi-structured interview process, the interviewer prepares a list of questions that are based either on literature search or objectives of the research that focus on guiding the conversation (Saunders et al; 2012).

The questions used in this interview were prepared in advance and were open ended so that they have no conditions or rigidity so as to give the researcher some form of flexibility to ask major questions directly, related to the objective of the study and any further explanation was sought when a need arose (Gilbert, 2008). Semi-structured interviews are in line with qualitative study which aims ''at looking for the rich and detailed information and not for the yes or no or agree-or-disagree responses'' (Flick, 2014:197).

The objective of using semi-structured interviews is stated by Matthews and Ross (2010:221) that, ''they are most typically associated with the collection of qualitative social data when the researcher is interested in people's experiences, behaviour and understandings of how and why they experience and understand the social world in this way''. Furthermore, semi-structured interviews were preferred because they can be undertaken on wide variety of situations of normal people, government officers, and company managers (Matthews and Ross, 2010). The objective of using participant observation is that the session was prepared by Saudi Consul of Engineer in the KSA, session was talking about DIGITAL CONSTRUCTION ENGINEERING AND MANAGMENET. In the city of Jeddah located in Prince Sultan street on 30th July 2017 at 8:00 Pm.

3.3. Sampling procedures:

This study used purposive sampling technique which means the selection of participants with purpose (Matthews and Ross, 2010). The researcher intended to collect the information from participants in Saudi Arabia who would be in a position to provide the needed information. According to Silverman (2014) the purposive sampling allows the researcher to choose research respondents because it illustrates some features or process in which we are interested in (Silverman, 2014).

The purposive sample of this study comprised interviewees from private and government construction companies. The government officers were four while three managers from private sector were selected and used from one economic sector of construction in Saudi Arabia. Engineers working in these construction corporations were interviewee participants. Also, it was approximately 24 guys from deferent background they are attend to the session maintained above such as; project manager, civil engineer, information system, architect, general manager, mechanical engineer, quantity engineer, construction manager, and surveyor.

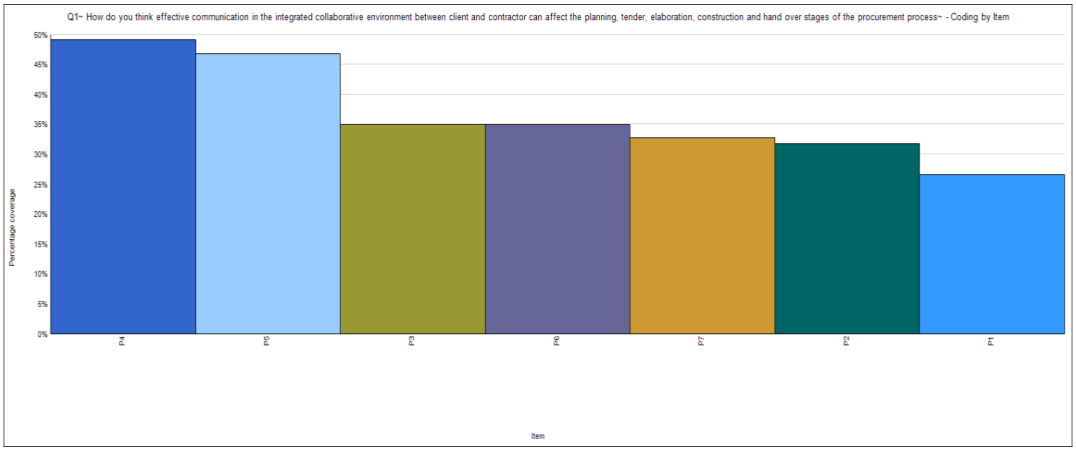
3.4. Data analysis techniques:

The transcript of data was carried out by transcribing the interviews and other recorded material while the researcher ensured that the material was transcribed in its entirety so as not to miss any valuable information. Data analysis was done using Nvivo 10 software. Using Nvivo required recording the whole interview from the audio recorder to the computer. According to Welsh (2002) the data analysis tools have the potential to analyse and shape the collected data in effective and efficient ways, thus they are recommended for time saving and accuracy. Furthermore, the use of Nvivo facilitates researchers to discover and understand groupings of the huge data from interviews into a meaningful and systematic manner (Hair et al, 2007).

 DOI 10.3311/CCC2018-091

4.0. Result and Discussion**:**

Effective communication can achieve the main challenge between the client and contractor when the communication is used in the right way. Where there is effective communicate between client and contractor; it will add value to the procurement processes and it will establish a string foundation to have a collaborative environment during the planning tender, elaboration, construction and hand over stages (Sperling et al., 2008).



Participant Q1

The study investigated the features of integrated collaborative environment and the contributing aspect that influences the interrelation on the processes between client and contractor in term of effective communication by using content analysis technique, as indicated on the chart above and the result in particularly show the following:

- **Understanding information more clearly:** The interviewees explained that misunderstanding can affect planning, tendering, elaboration, construction and hand over stages in the procurement processes. This will affect directly planning and other stages of the project. The procurement manager stated:

> "*Misunderstanding during communication between client and contractor will have big impact on the planning of the procurement process, for example, I can give you an example from my experience. Sometimes verbal communication will give misunderstanding. Therefore, it will affect the life cycle of the whole project by delaying the planning, construction and hand over stages''* Procurement Manager 1.

The Kingdom Saudi Arabia has economic influence over 26 countries in the Middle East.it is also the biggest economy over the Gulf countries. The Saudi construction industry employees over eleven million people. More than 80 per cent of eleven million are working in construction industry. Therefore, integrated collaborative environment by using digital technologies will add value to the planning, tender, elaboration, construction and handover stages in procurement processes (GLMM, 2014).

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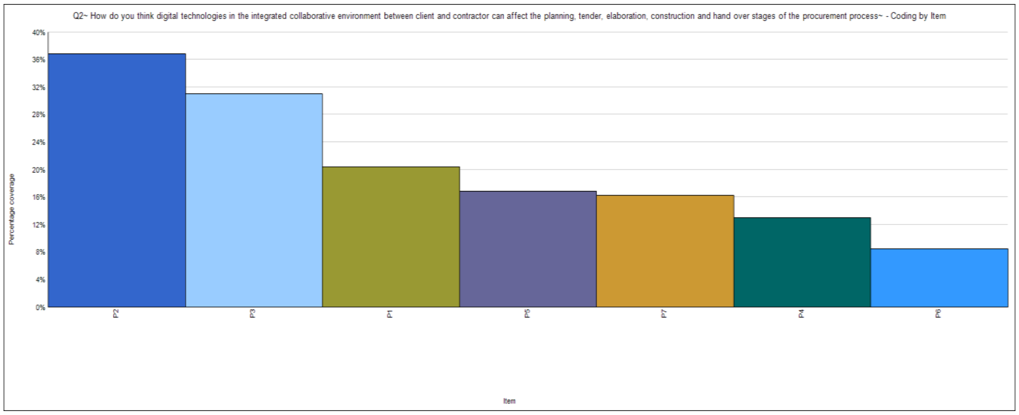

Participant Q2

- **Collaboration:** The analysis of the data on the digital technologies is indicated in the above figure. Building information modelling (BMI) as a collaborative way of working is supported by the digital technologies which engage additional capable methods of scheming. From this table, the interviewee explained that by using (BIM) it will affect planning, tendering, elaboration, construction and hand over stages in the procurement processes. The interviewee stated that:

, *"It is true. They can work together, they can link them to layers. For example, this layer is a block, it will measure immediately the quantity, and then it will be reflected directly on the excel sheet. So, we are saving so much time in all aspects, and this will affect also the planning stage''*. Coordination Manager 3

Using digital technologies in the construction industry can affect the environment in many ways: planning, tendering, elaboration, construction and hand over stages. However, currently, there is no work without application of technologies. This is because technologies save time and contribute to reducing the carbon dioxide (CO_2). Furthermore, this is required to support the work place by using the feature of digital technologies during the construction stage to save cost and time for the wellbeing of all stakeholders (Thomas, 2016). Recently, the construction industry has been addressing maximisation of quality with an emphasis on partnership, joint venture and strategic alliances. It has focused attention towards collaborative working between clients and contractors-shifting ideology from imposing and managing commercial pressures to improving and developing the innovation of the project and technologies. In addition, it has been attempting to react to a huge demand in internationalisation of the companies and manufacturing (Rowlinson, Zhang and Lu, 2013).

The formal and informal process to solving a problem between the client and contractor in early stage. However, conflict resolution a means of doing away with these conflicts manly depend on the way of communication channels used. That means effective communication can solve problem but in some cases there is a conflict between stakeholders. A simple part of conflict resolution is negotiation between the parties. In some case conflict resolution can be a formal procedure such as mediation, facilitation and arbitration. Integrated collaborative environment can be depicted as a process of any problem which may occur during life cycle of the project or even when the project is finished. This is because collaborative processes in shared vision allows for all the stakeholders to find out alternative means.

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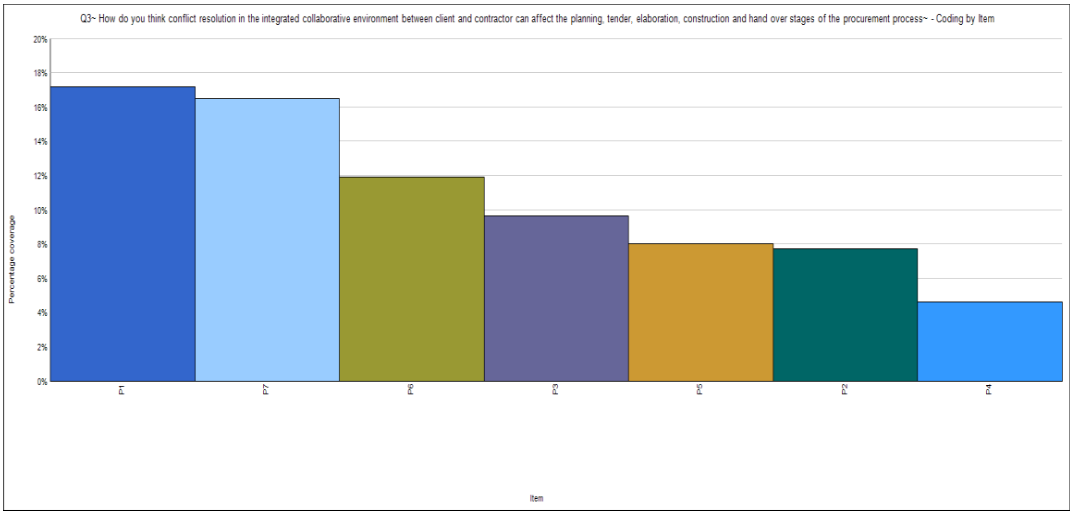
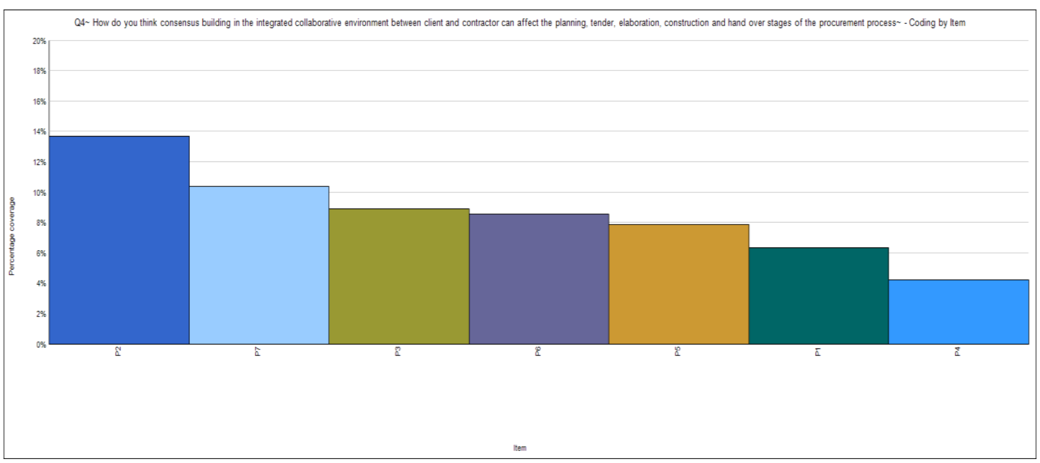


Participant Q3

Pre-identify problem: The participant viewed that pre-identifying a problem can affect planning, tendering, elaboration, construction and hand over stages in the procurement processes; which can be resolved using collaborative mechanisms. The collaborative way of working, is supported by this feature. Accordingly, in supporting this; the interviewees said:

> "*Usually conflicts create problems during the construction phase, in the planning everybody has to agree on one base plan, otherwise the conflict will arise, this is the client's needs, this is the contractor's point of view, this is the consultant, this is the project manager, we have to agree on this So conflict has to be resolved throughout the project in terms of planning stage".* Construction Manager 4

Consensus building is a collaborative problem solving. This is because client has his own team. In that case, the contractor has his own team which then needs to apply this concept to solve any issues. Usually consensus building can include complex interrelation such as international project which required a multiple organisation to involve. For instance, if there is a project and the material mansion during the tender stage are not in that market, is it is then important to use consensus building among all the stakeholders.

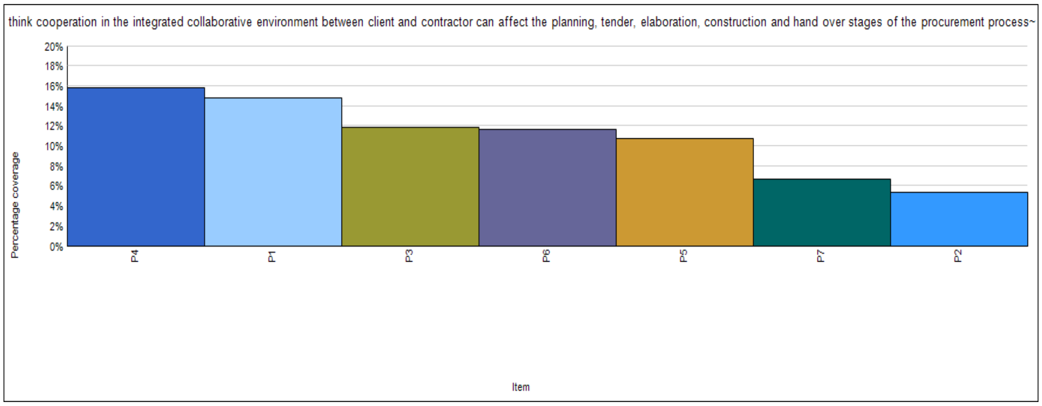


Participant Q4

Engagement of team member/stakeholders: The data analysed in the chart above indicated the result of the study which investigated the features of integrated collaborative environment and the contributing aspect that influence the inter relation on the processes between client and contractor in term of effective communication; particularly on the people. This feature was supported by the interviewee who stated:

> *''Let me tell you something, in so many ways, because construction is depending on methods statements; methods statements that vary between one person to another. Who is building the methods statements? It's the people who are building the projects. But, we believe that the best practice is that which achieves the target of the project, in terms of planning stage.''* General Manager 6

Cooperation as a team networking indicates the relation between the client and contractor by focusing on organisation theory. However, integrated collaborative environment emphasizes on workflow based on organisation collaborative rather than the organisation themselves. The concept of cooperation means that each part is working to a mutual end, sharing information and skills, and responding flexibility. Furthermore, cooperation applies in terms of degree of complexity, focusing of power balance and cover the requirement of integrated collaborative working.

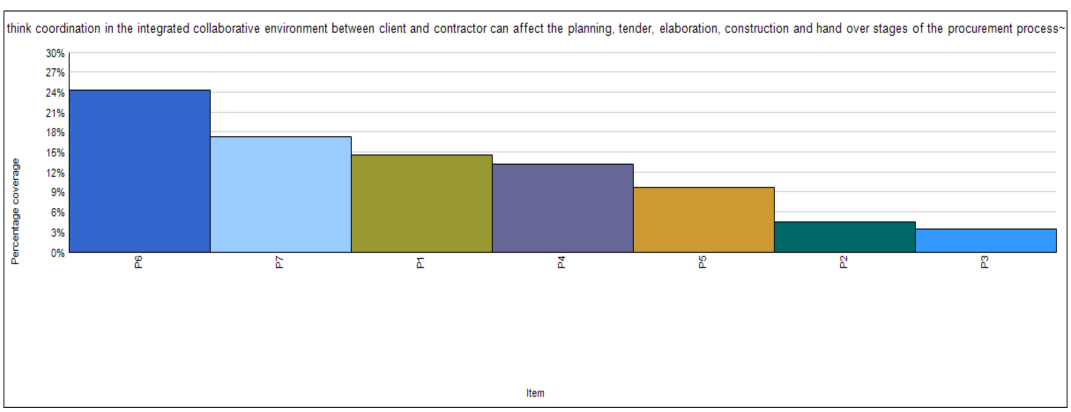


Participant Q5

Problem solving: By using the content analysis technique on the chart above the result shows the influence of the interrelation on the processes between client and contractor in terms of cooperation on a development behaviour. This feature is supported by the interviewee who stated:

> *"This is the top of cooperation, if you have, if any engineer, whether he is a project manager, a site engineer or just an ordinary clerk engineer; he has this problem-solving behaviour, the project will be totally enhanced at all stages of planning and tendering… you know, everything related to the project. This is very much affecting the procurement*''. Project manager 2

It is more difficult to coordinate the relation based on "common sense" or "tools". But the development of technologies with a good coordination principle can be success the environment in any project. However, coordination can shows that how people are working together. Nowadays, new technologies can explore the relationship between the stakeholders and how they might do with a new data/information available. Digital technologies make principles of coordination and how activities are working together have led to the achievement of main aim of construction industry. This is because it is based on a number of activities interlinked together to finish a project (Malone and Crowston, 1990).



Participant Q6

By using content analysis technique on the chart above the result shows the subject of the study in investigating the features of integrated collaborative environment and the contributing aspect that influence the inter relation on the processes between client and contractor in term of effective communication. In particular:

Enhancing decision making: The interviewee explained that decision making can affect planning, tendering, elaboration, construction and hand over stages in the procurement processes. This feature allowed the stakeholders to share data/information according the interviewee who said:

> *"It is very important to know what the client's requirements for the handing over procedures. And the same*

to be communicated and inform what is the amount of the bill. Some clients are asking to submit to the warranty certificate, submit the operation and maintenance manuals": project Manager 2

5.0. **conclusions:**

Is collaboration culture the way to solve the challenges in the KSA construction procurement processes if so then: How collaborative culture could enhance construction procurement processes efficacy during the project life cycle in the KSA?

6.0. **Recommendation:**

This study recommends that still the government need to improve the skills of them team, also to make sure that all contractor aware in his job, this is because the real situation in the KSA at this time unstable. Namely, by improving team skills of both side privet and government the result directly will element none add value activates. In addition, based on Saudi construction industry and because it has the biggest economy market in the Gulf countries, it is required to collaborate with client companies and contractors so as to put in administrative mechanism to improve the construction industry. Doing so, it can create a good opportunity for the companies and contractors to extend their construction activities in other Gulf countries and thus help earn income for its people and economic development of the country of the KSA.

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The Predicating determinants accessibility of credit small and medium enterprise in the construction industry in South Africa.

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Abstract

This paper focuses on determining the demographic and company profile that predict credit accessibility for small and medium construction enterprises (CSMEs) from banks in South Africa.The significance of CSMEs in the economy has been recognised. However, construction SMEs in many countries, in particular developing countries, are not performing well. One of the factors for poor performance is lack of credit accessibility to fund SMEs operations and expansion. Even those who get access to credit do not get adequate credit they applied for. A quantitative philosophy of research was adopted which is positivism approach. Hence, data was collected using, questionnaire survey from 179 CSMEs who were conveniently sampled. The questionnaire was developed from extant literature review. The demographic and company profile determinants predicting credit accessibility were identified and modelled with full credit accessibility and credit accessibility to the SMEs irrespective of the amount obtained. The data was analysed using statistical package for the social sciences (SPSS) version 22. Binary logistic regression analysis was used to analyse the predictors of credit from the banks. The results revealed that the credit accessed irrespective of the amount and those who did not receive credit when modelled with the predictors suggested not significant predictors. However, when the predicators were modelled with full and partial credit the results established that, age group, current position in the organization, tax number and location were good predicators of partial credit. The gender of the respondent, type of business ownership and collateral (security) did not predict full credit being obtained.The study cannot be generalised across South Africa because the study was only conducted in the Gauteng province. The value of this study informs CSMEs owners and managers in the construction industry to provide, their age, current position in the organization when applying for credit. Furthermore, they should provide the tax number and the location of the business in order for them to improve their chances of obtain full credit from banks.

Keywords: credit accessibility, determinants of credit accessibility, full credit, small and medium enterprises ;

1. Introduction

The term Small and Medium Enterprises (SME) covers a wide range of definitions which, varies from country to country. Some of the commonly used criteria are the number of employees, total net assets, sales and investment level. However, the most common characteristics in the definition is number of permanent employees. [1] defined SMEs as companies that have up to 300 employees and total assets and sales of up to $ 15 Million. However, in the South African context in the construction industry, small enterprise is defined as having less than 50 employees, having an annual turnover of less than R5million, while medium enterprises have between 51 and 200 employees and less than R20million turnover. It can therefore be justified that SMEs are defined differently from country to country (National

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Business Act, 2003). Despite the variance in definition SMEs contribute immensely to the economic gains in most countries including South Africa

Despite its importance to the economy in South Africa, small and medium construction enterprises (SME) sector is described as largely underdeveloped and lacking the managerial and technical skills and sophistication enjoyed by larger well established contractors. The SMEs are left on the periphery of the mainstream economy and do not participate fully in the economy [8]. [15] opined that lack of knowledge including knowledge of pricing procedures, contractual rights and obligations; law, management techniques and principles as well as technology were a challenge to SMEs.

It can further be stated that contractors registered in the lower grades of the Construction Industry Development Board (CIDB) [7] and [8] contractor register are small and medium. Hence, they are more likely to have limited formal education, which is based on a construction craft or trade training such as carpentry, plumbing, electrical installation and bricklaying. This training is probably in the form of learnership [7] and [3]. Furthermore, past studies in South Africa had revealed constraints and challenges of capacity and financial resources among SMEs [9]; [2]. [12] they inferred that SMEs are not able to access finance or credit hence it stifles their growth and capability.

It is accepted that SMEs are a vehicle of economic empowerment in the construction industry and other industries in South Africa. However, they are phased with numerous constraints to enable them maximize their economic potential. Furthermore, construction SMEs find it difficult to access the credit they applied for. It can be unequivocally indicated that there is lack of studies to determine the determinants predicting full credit and partial credit accessibility and also assessing whether the construction SMEs accessed the credit or not. Lack of consensus on the predicators of credit accessibility among SMEs is a problem that requires to be solved. The main aim of the study was to investigate credit accessibility among construction SMEs. This study is therefore guided by three specific research questions: viz;

- What factors prevent construction SMEs from accessing credit?
- What are the socio-economic and demographic predicators of full credit accessibility from financial institutions?
- What are the socio-economic and demographic predicators of credit accessibility from financial institutions?

Therefore the objectives of the study to answer the specific research questions were:

- To determine the factors that prevent construction SMEs from accessing credit;
- To assess the socio-economic and demographic determinants predicting full credit accessibility from financial institutions; and
- To evaluate the socio-economic and demographic determinants predicting credit accessibility from financial institutions.

2.0 Literature Review predictors to access to funds (CSMEs)

2.1 Selected Determinants of credit accessibility for small and medium enterprise

This section discusses the determinants of credit accessibility as per the reviewed literature;

2.1.1 Gender

According to [18] suggested that gender play a significant role to access credit. A number of studies have shown that female SMEs are more constrained than their male counterparts in SMEs in accessing credit.[4]and [5] in his study suggested that female SMEs face more obstacles while accessing credit compared to male counterparts.[15] analysed gender differences in accessing credit and explained that female are more financial constrained compared to their male counterparts in accessing credit.[5]and [2] indicated that access to credit is more oriented towards male than female.[8] in their study of SMEs with regards to the impact of gender on access to credit, established that female get credit easier compared to their male counterparts. It can therefore be argued that gender predicts credit accessibility.

2.1.2 Age group

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The assumption that a particular age group tends to behave and in a different way than other age groups. For instance, older owner/managers mostly appear to be at risk [17] and do not want to use bank loan. Younger owner/managers are perceived be innovative and good performers hence could attract credit accessibility. There are several studies that investigated the effect of age of applicant on access to credit, however there are mixed results, mainly on the significance of the variable. A study conducted by[17],[9] and [15] showed that age do not have significant effect on access to credit. [13] also found out that age and access to credit do not have significant relationship. However, contrary to the above findings, [17] demonstrated that age have significant effect on credit accessibility. [1] suggested that the positive of age group on access to credit prevails over the negative. Despite the mixed results it is hypothesised that age group will be a predictor of credit accessibility.

2.1.3 Current position

According to the report of [6] stated that the level of the position of the directors, manager, or the owner of the company will determine the loan or credit the organization can be secure, this is because credit seekers with higher position in the company and high management level can access loan or credit easily. Therefore it can be suggested that the current position of the applicant will predict credit accessibility.

2.1.4 Types of business ownership

[6], found that legal status influence the bank lending. [6] further stated that corporate status at start-up appears to be associated with a greater likelihood of bank lending. The existing empirical evidence supports the existence of a positive relationship between form of business ownership and credit leverage. For example, [12] found evidence supporting a positive relationship between credit leverage and sole trader on access to credit. Similarly, [17] and [13] suggest that sole traders are greater users of bank credit. Thus, the form of business ownership influences credit accessibility.

2.1.5 Tax Number

According to [14] pointed out that SMEs in the service sector reported a lower likelihood to register for tax than those in construction, agriculture, and manufacturing sectors. [8] indicated that SMEs employing workers were more likely to express a likelihood to register for tax than sole proprietors with no employees. Moreover, SMEs who kept complete financial records on paper and computer were more likely to report an intention to register for tax than those who did not keep such records. Furthermore, SMEs who agreed that Government gives a good return on taxes paid in the form of government services reported a much higher likelihood of tax registration. It can be suggested that when SMEs are offered incentives or the system is easy to work with they register for tax. However, it is suggested that tax registration is a path way to having a tax number, hence will aid in access to credit from the financial institutions.

2.1.6 Location of the business

The lenders who are geographically closer to their business owner are capable of utilising available qualitative information to establish the credibility of their customers for credit accessibility. [5] spotted that the location of the firm is dependent on access to the financial institution. According to [9] they indicated that the geographic nearness of the firm to the financial institution had an influence with the firm accessing credit. This is supported by [8] who affirmed that SMEs located in the towns are successful in accessing credit compared to those found in the countryside. These studies therefore propose that the location of the business predicts credit accessibility.

2.1.7 Collateral security

In lending agreements, collateral is a borrower's pledge of specific property to a lender, to secure repayment of a loan [10] and [5], [15]. The collateral serves as protection for a lender against a borrower's default - that is, any borrower failing to pay the principal and interest under the terms of a loan obligation. If a borrower does default on a loan (due to insolvency or other event), that borrower forfeits (gives up) the property pledged as collateral - and the lender then becomes the owner of the collateral. The study conducted by [2] and [3], established, that collateral is a major determinant of credit accessibility by SMEs.

3.0 Operationalisation of the conceptual framework

The model is made up of dependent variables which were dichotomous; credit accessibility defined by (I did access credit and did not access credit) and (I accessed full credit and I accessed partial credit) and independent variables which are; gender, age group, current position, type of business ownership, business tax number, location of

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the company and collateral. The mathematical model 1 which is a general equation for logistic regression was used for this study to predict the independent variables influence on credit accessibility.

This can be written as:

$\ln(p/1\text{-}p) = \beta0 + \beta1x1 + \beta2x2 + \ldots + \beta kxk$……………………………………………………………………..(1)

The specific logistic regression for the study was modelled as follows**:**

$\ln(p/1\text{-}p) = \beta0 + \beta1Gender + \beta2Age\ Group + \beta3CurPostion + \beta4TypesBusOwnSh + \beta5TaxNo + \beta6LocBus + \beta7Collateral\ \varepsilon$

4.0 Research method and design

The questionnaire included personal questions on age, gender, population group, education qualification, marital status, current position and years of experience in business. Other sections included company profile namely location of the business, ownership, construction industry development board (CIDB) [7] grading, number of full time employees. Requirements of financial institutions e.g. collateral and tax number. It is worth noting that not all these variables were included in two models for credit accessibility i.e. to predict full credit they applied for or any credit at all. The dependent variable for full credit was informed by, whether the SMEs received full credit or part of the credit. On the other hand the study also established whether the SMEs received the credit or did not receive credit. Statistical Package for Social Sciences (SPSS) version 22 was used to perform the binary logistic regression analysis on this dichotomous outcome.

A binary logistic regression model with dichotomous responses as dependent variables of Yes or No were modelled. Yes response was defined as having accessed full credit and No accessed part of the credit. The second dependent variable defined "Yes" as accessed credit and "No" did not access credit. For analysis to be conducted, the responses of the dependent variables were coded as 1 and 0, for "Yes" and "No" respectively. The independent variables of the logistic regression model were coded. They conformed to the demographic and socio-economic characteristics of the SMEs: *gender* if male 1 and female 2; *age group,* 30 years and below 1, 31 years to 39 years 2, 40 years to 49 years 3 and 50 years and above 4; *current position*, director 1, owner 2, manager 3 and manager/owner 4; *ownership*, sole proprietorship 1, partnership 2, limited partnership 3, limited Liability company 4, corporation (for-profit) 5; *tax number* No, 0 and Yes, 1; *location of business,* city of Johannesburg Metropolitan Municipality 1, city of Tshwane Metropolitan Municipality 2, Ekurhuleni Metropolitan Municipality 4, West Rand District Municipality 4; *collateral* No, 0 and Yes, 1.

Logistic regression is recommended over linear regression when modeling dichotomous responses and allows the researcher to estimate probabilities of the response occurring (Hosmer and Lemeshow, 2004). The logistic regression equation takes the following form

$\ln(p/1\text{-}p) = \beta0 + \beta1x1 + \beta2x2 + \ldots + \beta kxk$……………………………………………………………………..(1)

Where p is the estimated probability of passing, and x1, x2, …, xk are independent variables.

5.0 Results and discussions

Table 1 indicates that male respondents were the majority than female respondents, at 63% to 37% respectively. Majority i.e. 51% of the respondents were in the age group between 40-49 years old. 82% of the respondents occupied the position of owners. 98% of the SMEs are sole proprietors. Furthermore, majority i.e. 41% of the SMEs were located in the city of Johannesburg metropolitan.

Table 1: Profile of respondents and organization

Gender	Frequency	Percentage
Male	112	63%
Female	67	37%
Age group	**Frequency**	**Percentage**
30 years and below	2	1%
31-39 years	49	27%
40-49 years	92	51%
50 years and above	36	20%
Current position	**Frequency**	**Percentage**
Director	29	16%
Owner	146	82%
Manager	3	2%
Manager/owner	1	1%
Ownership	**Frequency**	**Percentage**
Sole proprietorship	175	98%
Partnership	2	1%
Limited partnership	1	1%
Limited liability company (LLC)	1	1%
Location of company	**Frequency**	**Percentage**
City of Johannesburg metropolitan	74	41%
City of Tshwane metropolitan	42	24%
Ekurhuleni metropolitan	34	19%
West Rand district municipality	29	16%

The result in Table 2, 21.91% i.e. 39 of the respondents received part of the credit they applied for and 78.09% i.e. 139 of the respondents obtained the full credit. It can be indicated that some of the SMEs did not receive the full credit they applied from the financial institutions. The finding is in line with the theory of credit rationing, which was informed by [11]. This theory can be argued to be the demand of funds by small medium and micro enterprises (SMMEs) and the supply of funds [5]. Furthermore, one respondent did not indicate whether the company received full or partial credit. However, Table 5 justifies this finding as the respondent indicated the company did not receive credit at all.

Table 2: Full or partial credit accessed

Credit accessed	Respondents	Percentage
Accessed partial credit	39	21.91%
Accessed full credit	139	78.09%
Total	**178**	**100.00%**

The results in Table 3 indicates that of the seven demographic and socio-economic independent variables modelled to predict full credit accessibility. Age group 40-49 years were likely to receive full credit than applicants who were in the age group 30 years and below. This finding corroborates with the findings of [19] and [14] and [20]. It is interesting to note that applicants who are 30 years and young are have a likelihood of receiving partial credit than full credit. The current position predictor achieved a level of significance (p-value) of less than 0.050. This reveals that the variable predicted full credit accessibility. The finding is in line with the findings of [6] and [11]. However, it is interesting to note that no category of the current position in the SMEs stated, predicted full credit accessibility. The level of significance (p-value) were greater than 0.05 for all categories of current position held in the organization.

Furthermore, the study found that when the SMEs provided their tax number they had a greater probability of accessing full credit, compared to those who do not provide there tax numbers. The level of significance was less than 0.05 at 0.015 hence a strong predictor. Furthermore, the SMEs whose premise were in Location, Ekurhuleni metropolitan municipality in Gauteng province had a higher probability of getting full credit, compared to SMEs in the city of Johannesburg metropolitan municipality. This predicator was significant at 0.043 which was less than 0.05. The odds of getting the full credit was 0.247 more those in city of Johannesburg. This finding is supported by [4] and [9]. [6] and [20] indicated that the geographic nearness of the firm to the financial institution had an influence with the firm obtaining credit. On the other hand [9] indicated that those in urban areas were likely to obtain credit than those in rural areas. Therefore it can be suggested that the location of the business is vital for credit accessibility. The gender of the respondent, and type of ownership did not predict full credit accessibility. Furthermore, it is imperative to mention that collateral was not statistically interpreted in the output result of SPSS despite being included in the analysis as a predictor. However, prior to testing this model, the goodness of fit of the model was tested which indicated a good fit. This result was justified by the Hosmer and Lemeshow test. The significance of the model was greater than 0.05 at 0.271. The result suggests that the independent variables were fitting in the proposed theoretical model.

Table 3: Predictors of accessing full credit

Variable	Exp. (B) Odds ratio	95% C.I. for EXP (B)Lower	95% C.I. for EXP (B) Upper	P-value
Gender (1)	2.102	0.929	4.757	0.075
Age group				0.133
Age group 31-40 years (1)	135383335.572	0.000	.	0.999
Age group 40- 49 years (2)	0.269	0.079	0.916	0.036
Age group 50 years and over (3)	0.668	0.215	2.074	0.485
Current position				0.040
Current position owner (1)	0.000	0.000	.	1.000
Current position manager (2)	0.000	0.000	.	1.000
Current position manager/owner (3)	2.191	0.000	.	1.000
Ownership				1.000
Ownership partnership (1)	0.000	0.000	.	1.000
Ownership limited partnership (2)	1.357	0.000	.	1.000
Ownership Limited Liability company (LLC) (3)	1.274	0.000	.	1.000
Tax number (1)	0.050	0.004	0.564	0.015
Location (municipality)				0.085
Location, City of Tshwane Metropolitan Municipality (1)	0.785	0.218	2.828	0.711
Location, Ekurhuleni Metropolitan Municipality (2)	0.246	0.063	0.958	0.043
Location, West Rand District Municipality (3)	0.707	0.175	2.863	0.627
	34707472280467732 00.000			0.999

Dependent variable: full credit accessibility (0=partial credit; 1=full credit) sig. at 5%

Table 4 deduced that only 0.6% of the SMEs did not have access to credit while 99.4% of SMEs had obtained credit. Therefore, the majority of the respondents obtained credit. However this finding is contrary to the findings of [9] who found that in South Africa only 27% of SMEs obtained bank loans while 73% did not obtain the credit

Table 4: Accessibility of credit and no credit accessibility

Access to credit	**Frequency**	**Percentage**
No did not access credit	1	0.6%
Yes I did access credit	178	99.4%
Total	**179**	**100.00%**

The results in Table 5 indicates that of the seven independent variables modelled to predict credit accessibility were not significant hence the null hypothesis cannot be rejected. The results in Table 6 indicate that; gender, age group, current position, type of business ownership, location of business, tax number and collateral were not good predictors of credit accessibility. The results indicated the level of significance (p-value) of each predictor variable were greater than 0.05. Furthermore, it is imperative to mention that collateral was not statistically interpreted in the output result

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of SPSS despite being included in the analysis as a predictor.

However, prior to testing this model, the goodness of fit of the model was tested which established a good fit. This was justified by the Hosmer and Lemeshow test. The significance of the model was greater than 0.05 at 0.988. The result indicates that the independent variables were fitting in the proposed theoretical model and therefore further statistical analysis could be conducted.

Table 5: Binary logistic regression, predictors of accessing credit

Variable	Exp. (B) Odds ratio	95% C.I. for EXP (B) Lower	95% C.I. for EXP (B) Upper	P-value
Gender (1)	1.547	0.812	2.947	0.184
Age group				0.376
31-40 years (1)	0.499	0.016	15.716	0.693
40- 49 years (2)	0.838	0.334	2.101	0.707
50 years and over (3)	1.557	0.695	3.486	0.282
Current position				0.526
Owner (1)	1050190579.980	0.000	.	1.000
Manager (2)	1665203759.364	0.000	.	1.000
Manager/owner (3)	6315003273.235	0.000	.	1.000
Ownership				0.994
Partnership (1)	0.000	0.000	.	1.000
Limited partnership (2)	0.000	0.000	.	1.000
Limited Liability company (LLC) (3)	1.733	0.000	.	1.000
Tax number (1)	0.324	0.045	2.353	0.265
Location (municipality)				0.587
City of Tshwane Metropolitan Municipality (1)	0.577	0.222	1.498	0.259
Ekurhuleni Metropolitan Municipality (2)	0.520	0.178	1.521	0.232
West Rand District Municipality (3)	0.499	0.169	1.470	0.207
	3470747228046773200.000			

Dependent variable: credit accessibility (0= no credit accessed; 1= credit accessed) sig. at 5%

Conclusions

The study elicited information from SMEs personnel who are conversant with the credit accessibility within their enterprise. The study found that SMEs are stifled from accessing credit because of lack of collateral/security, lack of cash flow statement and owners' equity. However, despite the constraints of accessing credit which could be a stumbling block to credit accessibility, the results suggest that majority of SMEs received credit whether full credit or partial credit. However, despite the SMEs obtaining partial credit it can hinder their progress. It can be suggested that when construction SMEs receive part of the credit they might apply for credit in other financial institutions or request financial assistance from friends in order to cover for the deficit.

The researchers established that for SMEs to access full credit from the financial institutions age group, current position in the organization of the respondent applying for credit predicated full accessibility. Furthermore, tax number and location of the business in the Gauteng province were also predicators of full credit accessibility. However, the gender of the respondent, type of business ownership and collateral (security) did not predict full credit accessibility by SMEs. However when the predicators were modelled with whether the SMEs received credit or did not receive credit the predicators were not good determinants.

Recommendations of the study

Based on the conclusions, the study recommends the findings to different stakeholders, that is:

Recommendations to government

The government needs to encourage construction SMEs to approach commercial financial institutions to apply for credit as majority of SMEs obtained credit from them. The notion that commercial financial institutions reject or deny SMEs credit should be argued with caution as this study indicates that majority of SMEs acquired their credit from commercial financial institutions.

The government needs to inform financial institutions not to be too stringent with collateral (security), owners' equity and cash flow statement as these are the constraints impeding SMEs from credit accessibility.

Recommendation to financial institutions

The financial institutions should be aware of this constraints construction SMEs encounter in accessing credit. Collateral (security), owners' equity and cash flow statement should not be mandatory requirements in order for SMEs to acquire credit. Other requirements should be suggested which will make it easy for SMEs to access credit.

Recommendation to construction SMEs

SMEs should be informed that they should provide the age, and current position in the organization of the person applying for the credit. Furthermore, they should provide the tax number and the location of the business in order for them to obtain full credit they apply for. However, it is worth indicating that SMEs should also be aware of the requirements that the financial institutions will request them to submit as they apply for credit.

Limitation(s) of the study

The study cannot be generalised across South Africa because the study was only conducted in the Gauteng province.

Further study

- Firstly, further research could determine if the findings of this research are consistent across different sectors. Since the study concentrated on SMEs in the construction sector only. A further research in other sectors will shed more light on the findings of this study;
- In addition, there is the need to replicate this research in other parts of South Africa to confirm if the results of this research can be generalized across the country;
- This study can also be carried out in other African countries for comparative purposes;
- Though the study establishes some predictors on access to full credit, not all the variables were good predicators. Therefore, a further study can be undertaken to justify this findings;
- The study proposes the use of stepwise logistic regression in future study; and
- A further research to test other independent variables not included in this study will be critical. The factors recommended for testing are marital status of the applicant, bank account statement and managerial ability of the respondents

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The relationship of risk assessment with project success: an empirical study of small and medium contractors in Gauteng, South Africa

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Abstract

Risk assessment (RA) is widely acknowledged to be linked with construction project success (PS). However, there is a lack of empirical evidence to support this perception. Therefore, the current study sought to fill the gap by establishing the relationship of RA with project success. A structured questionnaire was used to collect data from small and medium contractors (SMEs) who were conveniently sampled in Gauteng, South Africa. The data was analysed using the Statistical Package for the Social Sciences (SPSS) version 23, computing inferential statistics. The results revealed a statistically significant relationship between RA and PS; that PS was positively influenced by RA. This was an indication that RA in construction is an important risk management factor that enhance project management decision making and hence influence PS. This finding contributes to the body of knowledge on the subject of RA and management and provide guidance to contractors on the practical implementation of RA concerns for construction PS.

Keywords: Contractors; project success;relationship; risk assessment; South Africa

1. Introduction

Successful completion of project in construction is the most desirable for all organizations and involved stakeholders. Project success or failure in construction have long been themes of interest among researchers this, for over the past 20 years. Reference [1] indicated that a construction projects is said to be a failure when it failed to be delivered within predefined project objectives which include: deliver the project within the scheduled time, estimated project cost, achieving desired quality, and without accident or injury (Health and Safety). Failures could threaten the very existence of the company [2]. It was indicated in a report released by reference [3] that, on average construction projects ran 45% over estimated cost and 7% over scheduled delivery time, while delivering 56% below desired quality. It was further reported that only 12% of construction projects had finished on time and within the established budget. Reference [3] elaborated on depressing construction project failure rates between 50% and 70%. These findings are inclusive of projects undertaken by construction small and medium enterprises (SMEs). Reference [2] confirmed that the risk of not delivering the project within its set target in SMEs was higher than in larger enterprises. Studies conducted, revealed that many SMEs fail due to the lack of access to finance [1]; [4]; [5]. However, a study conducted by reference [6], revealed several factors explaining the high failure rate of construction SMEs among which risk management was one of the important factors that affected project success. Risk management is the process by which risks are identified, assessed and mitigative measures are formulated in order to minimize the adverse impact of risks on project objectives. Reference [4] indicated that risk assessment was one of the most important phases of the risk management process that risk assessment when conducted, increases the likelihood of project success. Furthermore,

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Reference [7] argued that the adoption of risk assessment and management practices are closely aligned with overall project performance. Reference [8] indicated that the poor delivery of South African construction projects was exacerbated by poor management and inefficient risk management application. Although there was high importance of risk assessment to construction project success, the adoption of these risk assessment methods in construction projects is inconsistent, especially among SMEs [6]. Lack of adoption of risk assessment could have a negative impact on the overall performance of construction organisations in South Africa, given that, as pointed out by references [8], and [9], some construction SMEs in South Africa do not implement risk assessment and management techniques as part of managing their projects. One of the probable reasons for the lack of adoption of risk assessment within the South African construction industry, especially among construction SMEs, has been the scarcity of empirical studies examining the relationship of risk assessment with construction project success. Therefore and based on the above observation, the current study aims to establish relationship of risk assessment with project success of construction SMEs.

2. Literature review

Criteria of project success

Reference [10] define a project as the accomplishment of a stated objective, which encompasses a sequence of activities and responsibilities that require resources. The Oxford Dictionary considers criterion as a standard or principle by which something is judged, or with the support of which a decision is reached. The Oxford Dictionary further explains success as an advantageous outcome or the acquisition of fame or prosperity. When merging these two notions, criteria of project success can be regarded as the set of principles by which advantageous outcomes can be accomplished within a set specification. Reference [11] posited that project success means different thing to different people. Reference [12] regard success as an imperceptible sensitive sentiment, which changes with dissimilar management outlooks, and with the stages of the project. Contractors, sub-contractors, designers, consultants and owners have specific criteria for assessing success. For instance, architects usually value aesthetics rather than building cost as the leading criterion for success. However, the client may consider other measures more. Additionally, even the same person’s perception of success can vary from project to project.

Project Success measures

Over the years, numerous studies have been conducted on project success, and most of them have suggested various dimensions for measuring project success. Reference [11] opined that project success is contrastingly viewed among researchers and practitioners. The conventional measures of time, cost, and quality known as the Iron triangle have been the leading success metrics in construction [13]. The Iron triangle is cited in nearly every study [14]; [15]; [16]; [17] on project success. Contrariwise, reference [18] posited that project success should not be limited to just the Iron triangle and the project management community need to be informed about this. Reference [13] indicated that while other definitions of project success have emerged, the iron triangle is constantly cited in the unconventional definitions.

In addition to the conventional measures, reference [19] supported that dimensions for project success should also encompass project psychosocial outcomes which involve the contentment of interpersonal relations with the project team. Individual dimensions such as participants’ satisfaction level are referred to as soft dimensions. The incorporation of satisfaction as a success metric is recommended by reference [20]. Furthermore, reference [21] suggested incorporating the absence of legal claims as a measure of project success. This indicates the importance of including safety as a success measure since it is logical to anticipate that if accidents materialise, both clients and contractors may be subject to financial loss, contract delay as well as legal claims. Reference [22] assessed project success extensively based on five criteria namely; maintenance cost, construction cost, time, safety and flexibility to users. Reference [23] stated that it is problematic to evaluate whether the performance of a project is a success or a failure owing to the fact that the notion of success remains unclear amongst project participants. According to [24], the project is a complete success if it attains the technical performance specifications to be executed, and if there is satisfaction regarding the project outcome among key users and project team members. In evaluating project success [25] included a range of criteria which included project meeting planned cost, time, quality of work, affability of the environment, transfer of technology, client and project manager’s satisfaction, and health and safety. Reference [25] defined project success based on four measures namely; achieving design goals, the value to the end user, the value to the organisation, the value of the technological infrastructure of the country and of organisations implicated in the development process. All these measures combined together provide the inclusive evaluation of project success.

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Regardless of the controversy in defining project success, this study follows the definition of project success as per [26]; [22]; [17]. This implies that the measures used in the study reflect project performance [14]; [15]. Reference [17] posited that the utilisation of a set of project success measures gives a considerable evidence of project performance than focusing on a single measure or a minor number of unplanned measures.

Conceptual framework for the study

Figure 1 represents the theoretical conceptual framework proposed in the study. The framework depicts the influence of the factor to project success as well as the hypothesized relationship between the constructs. On the other hand, project success is dependent on the level of practice of the factor namely; risk assessment. 1) determine the risk cause, duration, and volatility; 2) determine the probability of the risk occurring, impact, and classification consistency; 3) Establish the risk profile; 4) Assess risk by quantitative analysis methods; and 5) Assess risk by qualitative analysis methods were employed as the variables of project risk assessment. The relationship between the variables is discussed in the next section. For project success, reference [19] maintained that time, cost and quality have been the leading success metrics of construction projects. However, references [22]; [23] posited that project success should not be limited to just the traditional view. Reference [26] further suggested incorporating the absence of legal claims as a measure of project success. This indicates the importance of including safety as a success measure since it is logical to anticipate that if accidents and/or injury materialise. For the purpose of this study, time, cost, quality and health and safety were used as project success variables.

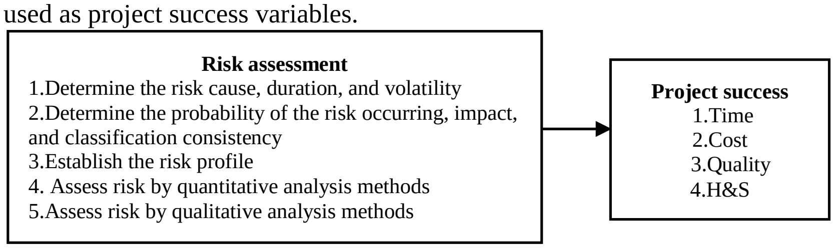

Fig 1. Conceptual framework

Relationship of risk assessment with project success

Reference [27] established that risk assessment activity makes a greater significant impact on the success of the project. The results indicated that adopting risk assessment has a substantial positive impact on project success as project staff was able to take actions to mitigate the occurrence of risks to a greater extent. Reference [28] tested the relationship between risk assessment and planned budget. The author established that there was an impact of risk assessment on project planned budget. In order to abate the rise of unsuccessful project completion in construction, the importance of risk assessment is a fundamental factor in an organisation risk management practices as emphasized by several authors [2]; [29]; [30] who affirmed the influence of risk assessment on the successful completion of a project. They reported that assessing uncertainties during the project, making use of the RM strategies and understand the business environment, significantly impact on project outcome. By assessing risk, managers can distinguish between acceptable and unacceptable risk events, and as a result enable them to capture and process information to assist them in the development of a risk management strategy [31]; [32]. Likewise, reference [33], indicated that risk assessment once performed, improved project objectives, accurate schedule, improved communication between relevant parties, and hence increased the chance of project success [33].

3. Methodology

The population of the study comprised of top management of SMEs (mostly owners, owner-managers, managers and project managers) who were selected from the Construction Industry Development Board (CIDB) register of contractors. In identifying potential respondents, the researcher ensured that all respondents were graded 1 to 6 (indicating small and medium contractors) and that they had a valid registration with the body they were from in order to participate in the study. Both secondary and primary data were used in the study. An extensive review of literature was carried out to gather secondary data included in the questionnaire which was later pre-tested. Primary data on the other hand was collected by administrating a questionnaire, via personal hand delivery method.

The survey consisted of forty-two statements/measures addressing nine risk management factors of which risk assessment comprised of five statements/measures. Following the questionnaire pre-testing, the final refined version of the questionnaire was distributed to 225 conveniently sampled SMEs using personal hand delivery and collect method of which 187 questionnaires were returned of which 6 were excluded from the study due to various ambiguity (questionnaire incorrectly answered, respondents' information missing and inadequate information provided). Consequently, the remaining 181 questionnaires were deemed usable representing approximately 80% response rate.

SPSS version 23 was employed computing descriptive statistics, Exploratory Factor Analysis (EFA) and Multiple Regression Analysis (MRA). EFA was performed to gather information about the uni-dimensionality of the variables, to confirm their validity and reliability using Oblimin with Kaiser Normalisation rotation and to assess the strength of the interrelationship among the variables. MRA was conducted to ascertain the relationship of monitoring and review with project success by determining the influence monitoring, review and continuous improvement on project success.

The measurement instrument was also tested for validity and internal consistency. Validity was ensured as a result of conducting an extensive literature review by consulting previous related studies, this was requisite to specify the variables. The questionnaire was reviewed and revised by experts (academics, researcher's promoter, and a professional statistician) before the pilot study took place. Internal consistency was tested using Cronbach's Alpha. A generally agreed upon minimum limit for Cronbach alpha is 0.70 [34]. However, a cut-off value of 0.60 is common for exploratory research and values closer to 1 suggest good reliability [35]. For this study, a cut-off value of 0.60 was adopted as used by [34].

3. Results and discussion

This section of the study reports on demographics, exploratory factor analysis and multiple regression analysis results. Descriptive statistics were used to analyse the profile of the respondents and the company. Exploratory Factor Analysis (EFA) was used to gather information about the unidimensionality of the variables. Multiple Regression Analysis (MRA) was used to determine the influence of risk assessment on project success.

Demographic results

Results revealed that among the respondents, 81.80% was male while 18.20% was female, 87.56% were either owners or manager of their enterprise, 56.40% were African/Black, had either matriculation (22.70%) or a certificate (20.40%), 43.10% of respondents had 10 years' or less experience in construction. Furthermore, it was found that 37.60% of SMEs were subcontractors or general contractors (31.50%), working mostly in Johannesburg (41.40%) and Tshwane (30.90%) Metropolitan Municipalities. Nevertheless, the subcontractors either operated for the main contractor or were sole trade contractors.

Results from EFA

Risk assessment was subject to EFA using SPSS version 23 which was used to gather information about the unidimensionality of the variables as well as to evaluate its reliability, discriminant validity and convergent validity. The Cronbach's Alpha of each measure ranged from 0.892 to 0.908 with an overall Cronbach's alpha value of 0.908 (Table 1). These results were all greater than the recommended value of 0.6 which indicated good reliability [36].

Table 1. Cronbach's Alpha of risk assessment measures

Code	Risk assessment measures	Cronbach's Alpha (0.908)
RA1	I/We determine the risk cause, risk duration, risk volatility.	0.890
RA2	I/We determine the probability of the risk occurring, the impact, classification consistency, i.e. high/medium/low	0.892
RA3	I/We establish the risk profile e.g. high probability/high impact, high probability/low impact.	0.871
RA4	I/We assess risks by quantitative analysis methods e.g. Probability, sensitivity, scenario, simulation analysis.	0.875
RA5	I/We assess risks by qualitative analysis methods e.g. Direct judgement, comparing option, descriptive analysis.	0.908

Results of correlation matrix coefficient in Table 2 revealed that the coefficient ranged from 0.478 to 0.756. They were all greater that the suggested cut-off value of 0.30, indicating that the four measures (RA1, RA2, RA3, RA4, and RA5) were good measures of the factor. These values were all above the recommended value of 0.60, suggesting good reliability [34]

Table 2. Correlation matrix for risk assessment measures

		RA1	RA2	RA3	RA4	RA5
Correlation	RA1	1.000				
	RA2	**0.756**	1.000			
	RA3	**0.700**	**0.684**	1.000		
	RA4	**0.697**	**0.683**	**0.771**	1.000	
	RA5	**0.478**	**0.479**	**0.715**	**0.684**	1.000

The KMO measure of sampling adequacy in Table 3 was 0.849 which was above the cut-off value of 0.6. Furthermore, Bartlett's Test of Sphericity was statistically significant at p=0.000 (<0.05), supporting the factorability of the correlation matrix [35]. These results indicate the factorability of the data set.

Table 3. Test of data factorability

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.849
Bartlett's Test of Sphericity	Approx. Chi-Square	629,155
	df	10
	Sig.	0.000

Results of EFA further evinced that of the five measures expected to measure risk assessment, only one measure had an eigenvalue above 1 (3.669). It explained 73.38% of the variance and accounting for 73.38% of the total variance. Since only one component was extracted, the solution cannot be rotated as it shows that this component is meaningful and it defines only a one-dimensional component as indicated by reference [37]. Therefore, sufficient evidence of convergent validity was provided for this construct.

Table 4. Percentage variance explained-risk assessment

Component/Item	Eigenvalue	% of explained Variance	Cumulative %
1- RA1	**3.669**	**73.379**	**73.379**
2- RA2	0.635	12.695	86.074
3- RA3	0.251	5.013	91.087
4- RA4	0.236	4.720	95.807
5- RA5	0.210	4.193	100.000

In addition, the decision to retain only one component was based on Kaiser's criterion by looking at eigenvalues greater than 1. Using Catell's (1966) scree test, it was decided to retain one component for further investigation. This was further supported by the results of principal axis factoring which revealed that the four measures loaded strongly together on one component. Their factor loadings presented in Table 5, were greater than the recommended value of 0.40, as suggesting by references [35]; [36].

Table 5. Component matrix for risk assessment measures

	Component
	1
RA3	0.900
RA4	0.899
RA1	0.850
RA2	0.843
RA5	0.777

Hypothesised relationship

The relationship between project success and risk assessment was hypothesised based on the results from EFA in support with reviewed literature. The null (Hypothesis 0) and alternative hypotheses (Hypothesis 1), which were tested using multiple regression analysis, include the following:

Hypothesis 1_0: Risk assessment does not influence project success; and

Hypothesis 1: Risk assessment influences project success

Results from MRA

Multiple Regression Analysis (MRA) was conducted to establish the relationship of risk assessment with project success by determining the influence of risk assessment on project success. The Regression results are presented in Table 6. It is shown that one measure (RA2) of risk assessment was found to be significant (i.e., p=0.000<0.05), making the largest significant contribution of 56% (beta=0.566). The results in Table 7 show risk assessment explained 19% (R^2=0.186) of the variance in project success at SMEs level. This suggested that risk assessment was not a good predicator of project success because of the low R^2 achieved.

Table 6. Coefficients- Influence of risk assessment on project success

Model	Unstandardized		Standardized	Sig.	Zero-order correlations
	B	Std. Error	Beta		
(Constant)	18.836	0.394		0.000	
RA1	-0.057	0.151	-0.044	0.706	0.246
RA2	0.794	0.158	**0.566**	**0.000**	0.398
RA3	-0.268	0.157	-0.221	0.090	0.153
RA4	0.038	0.171	0.027	0.826	0.210
RA5	-0.005	0.141	-0.004	0.973	0.107

Table 7. Model summary- Influence of risk assessment on project success

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
	0.431	0.186	0.163	1.34992

However, the ANOVA results in Table 8 indicated that the model reached statistical significance at p=0.000 (i.e., <0.05). This indicated that project success was influenced by one measure (RA2) of risk assessment and that the influence was significantly different from the value of 7.997 (F value). Thus, the null hypothesis ($H1_0$) that risk assessment does not influence project success could not be supported. This means that the hypothesis (H1*)* could not be rejected.

Table 8. ANOVA- Influence of risk assessment on project success

	Sum of Squares	**df**	**Mean square**	**F**	**Sig.**
Regression	72.868	5	14.574	7.997	0.000
Residual	318.900	175	1.822		
Total	391.768	180			

The relationship between risk assessment and project success was found to be significant, indicating that risk assessment positively influenced project success. This finding was supported by the study of reference [37]; [28]; [38] where it was found that project risk assessments enables project risk responses and mitigation strategies used effectively and avoid project cost overrun, delays and ensure project completion within the specified period. In addition, reference [28] established that there is a positive impact on risk assessment and project planned budget. Likewise, the current result is supported by the study of reference [33] which indicated that risk assessment conducted, increases the project performance in achieving project set goals. These findings imply that SMEs project risk assessment should be done effectively by competent officers to identify project risk facing SMEs projects and achieve project performance and that given the high failure rates associated with construction projects, lack of prudent for organisations to improve their ability to manage their construction project risks lead to projects failure. The findings failed to concur with reference [27] who contradicts the findings by indicating that most SMEs project failed to assess risk measures leading to poor construction SMEs project performance in terms of timeliness, profitability, costs and project schedules. Another study contradicting the current findings is that of reference [39] although it was indicated that all risk management practices namely; risk identification, risk assessment, risk response planning, and risk monitoring and control are required for project performance and project success, it was statistically established that there is an insignificant relationship between risk assessment and project success, suggesting that risk assessment negatively influences project success. This result indicates that risk analysis practices should be limited to avoid a negative impact on project scheduled time and budget.

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4. Conclusion

The main objective of the study was to determine the relationship of risk assessment with project success of small and medium construction enterprises to in Gauteng, South Africa. Through a questionnaire survey among SMEs respondents in Gauteng, it was found that there is a positive significant impact of project risk assessment on project success that risk assessment leads to success in construction projects of SMEs. The current finding provides guidance to contractors on the practical implementation of RA concerns for construction PS.

The study recommends that upper management of SME projects should increase the level of project risk assessment as it enhances the risk management activities. The study recommends that a further study should be carried out to investigate the effects of other risk management strategies on project performance of SMES not discussed in this study such as risk identification, risk responses, monitoring and review. A further study should be carried out to determine strategies that should be adopted to maintain the positive effects of risk management strategies on the project performance of construction SMEs.

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Using Historical Data of Economic Variables in Investigating Variations in Building Construction Cost Index

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Abstract

The construction economy is exceptionally dynamic. Any variation in the prices of raw materials, labor, regulatory costs, and energy can have a major impact in the construction industry and make it difficult to control costs especially in large scale, long term and complex projects. Building Construction Cost Index (BCCI) is used in cost estimation of buildings and is defined as the measure of the changes in the cost of construction input items relative to the average price level of a base year. Therefore, it is important to understand the influencing factors and the impact of input variations in BCCI for limiting potential financial risks in construction projects. This study aims at investigating whether the historical data of different economic variables is useful to figure out the variations in BCCI. Data is obtained from the publications of the Turkish Statistical Institute to understand the relationship between BCCI and three factors including domestic producer price index, consumer price index and construction labor input index. In addition, the strength of the relationship between BCCI and aforementioned factors are analyzed via statistical analyses.

*Keywords: Building construction cost index; domestic producer price index; consumer price index; construction labor input index; statistical analyses***.**

1. Introduction

The statistics show that the total value of new U.S. construction between 2008 and 2017 is around 1.23 billion U.S. dollars and the estimated value of construction spending to Gross Domestic Prize (GDP) ratio is around 6.4% in 2016 [1]. The fact that construction industry is one of the major industries in any country, it is important to estimate the total spending as well as the cost of input items that might change the overall spending in the construction industry. Therefore, several indexes have been introduced to estimate the construction costs. The Construction Cost Index (CCI) is defined as the weighted aggregate of average prices of constant quantities of common labour, standard structural steel, portland cement, and lumber whereas Building Construction Cost Index (BCCI) is defined as a measure of the changes in the cost of input items used in construction by periods. BCCI covers 12 items for labor cost and 109 items for material, which is one of the main inputs for estimating the building construction cost and budgeting of capital projects. Therefore, it is important to understand the influencing factors and the impact of input variations in BCCI. The aim of this study is to examine whether the historical data of different economic variables are useful to explain BCCI variations in Turkey. Historical data of 3 variables including Domestic Produce Price Index (DPPI), Consumer Price Index (CPI) and Construction Labor Input Index (CLII) are obtained from the publications of Turkish Statistical Institute (TSI) for the period between 2005 and 2017. Statistical analyses are conducted to investigate the relationship as well as the strength of the relationship between the variables and BCCI.

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The following sections present the research background and describe materials and methodology. Then findings are presented and discussed.

2. Research Background

Construction cost is still an unknown territory in which several variables might have direct or indirect effects, and, thus, investigating the effects of different variables on the CCI has received attention among researchers. Taylor and Bowen [2] analyzed the Index of Building Cost and concluded that the demand for construction has a dominant effect on the construction price level and construction supply capability has a long-term effect on the price movements. Skitmore [3] found a positive relationship between the new orders representing the construction demand and price level. Tender Price Index (TPI) also has been used as an indicator of construction cost level in the United Kingdom, Hong Kong, and Singapore [4]. Ng et al. [5] used the pattern of changes in eight explanatory variables (best lending rate, building cost index, consumer price index, gross domestic product, gross domestic product of construction industry, implicit gross domestic product deflation, money supply, and employment rate) for predicting the direction of changes in the Hong Kong TPI. Wong and NG [6] stated that the building cost index, gross domestic product, and gross domestic product in construction have explanatory value for predicting the TPI. Fellows [7] indicated that interest rates, investment intentions, architect's new commissions, production drawings, enquiries, orders, expected volume of work, and building cost can be the explanatory variables of the construction price in the U.K. Akintoye et al. [8] summarized unemployment level, construction output, industrial production, and the ratio of price to cost indices in manufacturing as the consistent leading indicators of the TPI.

In addition to understanding the parameters that influce the CCI, there have been many studies carried out to forecast the variations in the CCI. Williams [9] used the trends in the CCI, prime lending rate, housing starts, and the months of the year as the inputs of back-propagation network models to predict changes in the CCI. It is concluded that the CCI prediction is a complex problem, and, thus, it cannot be accurately predicted by the neural network models. Ashuri et al. [10] conducted a research to empirically examine whether the time series information on the economic, energy, and market variables is useful to explain the CCI variations.The results of the study showed that the information available from historical data on consumer price index, gross domestic product, crude oil price, housing starts and employment level in construction is useful to explain variations of the CCI. Moreover, Ashuri and Lu [11] created univariate time series models to forecast the CCI whereas Shahandashti and Ashuri [12] used multivariate time series models to forecast the CCI. Hwang [13] proposed two dynamic univariate time series models to predict the CCI. Moon and Shin [14] concluded that Vector Error Correction Model (VECM) showed better predictive ability than a cointegrated vector autoregression model and the advantages of query frequency over conventional economic indices could prove to be beneficial for forecasting purposes. Zhang et al [15], created a network approach in which time series is firstly converted into a visibility graph and future values were forecasted relied on link prediction. The researchers concluded that the proposed method is efficient to provide considerably accurate CCI predictions. Although many researchers have investigated the CCI and TPI from different perspectives, there is still a lack of research with respect to understanding the BCCI that has 12 items for labor cost and 109 items for material affecting the index, and, thus, is more unpredictable than the CCI. Therefore, there is still a gap which investigates the most influential variables on the BCCI.

3. Materials and Methodology

3.1. Data

In this study, annual quarterly data of the BCCI, DPPI, CPI and CLII are taken into account and the data is gathered from the publications of the TSI for the period between 2005 and 2017. It should be noted that the TSI announces the results of the BCCI and the CLII to the public on the 20th day or consequent working day of the following month of the quarter. Therefore, the data with respect to the last quarter of the year 2017 was not published as of this study was conducted, and, thus, the authors were not able to include it in the study. It should be noted that the results of the DPPI and the CPI are monitored monthly by the TSI, however, the fact that other variables are provided quarterly, the aforementioned variables are also converted to quarterly values by calculating the average value of previous three months.The descriptions of three economic variables are summarized in Table1.

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Table 1. Description of Variables.

Variable	ID	Description
Domestic Produce Price Index	DPPI	Domestic Producer Price Index is a measure of the change in the prices of goods and services sold as output by domestic producers in a given reference period
Consumer Price Index	CPI	Consumer Price Index measures the changes of the current retail prices of goods and services purchased by consumers over a given time period
Construction Labor Input Index	CLII	Construction Labor Input Index is a measure of employment which is defined as the total number of persons who work in the observation unit, as well as persons who work outside the unit who belong to it and are paid by it

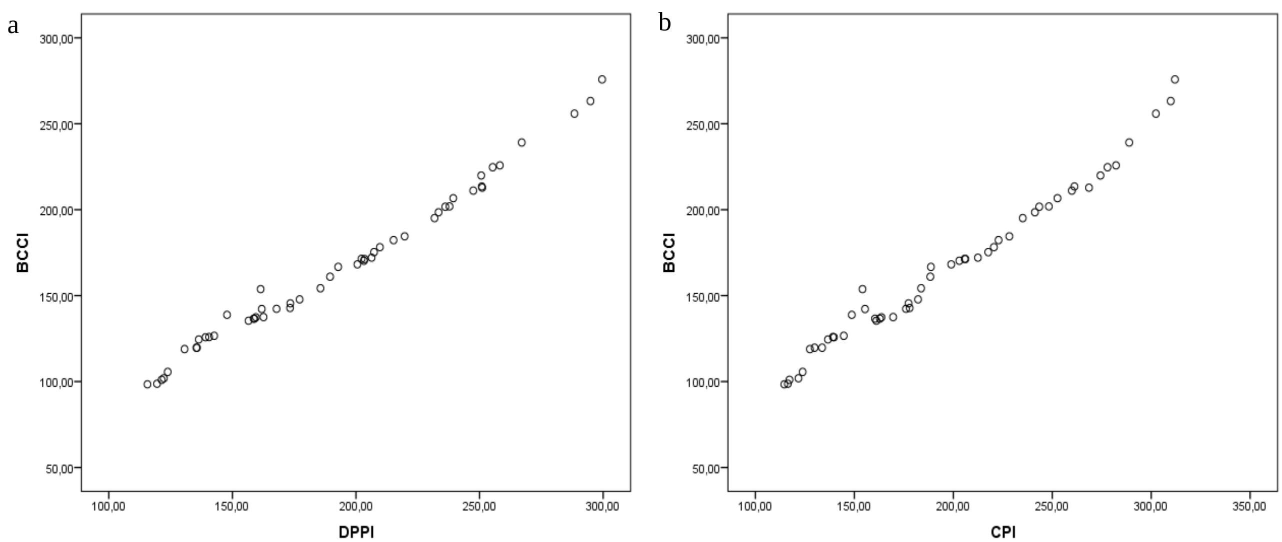
3.2. Methodology

Statistical analyses were carried out to understand the relationship between the BCCI and three variables including domestic producer price index, consumer price index and construction labor input index as well as investigating the strength of these relationships.

Firstly, the scatter plots were created to understand whether there is a linear relationship between the variables. Then, the Shapiro-Wilk tests were conducted to evaluate the normality of variables. The results of both analyses were used to select the applicable correlation coefficient. If there is a linear relationship between variables and variables are normally distributed, the Pearson correlation coefficient will be selected. Therefore, the Pearson correlation coefficients were calculated both to understand the direction of the relationships and to measure the strength of the relationships.

4. Findings

To investigate the relationship, firstly, the scatter plots of the BCCI and three variables were created. Then, Shapiro-Wilk normality test were conducted. As can be seen in Figure 1, the BCCI has a linear relationship with the DPPI, CPI and CLII. Therefore, it can be said that there is a correlation between BCCI and other variables.



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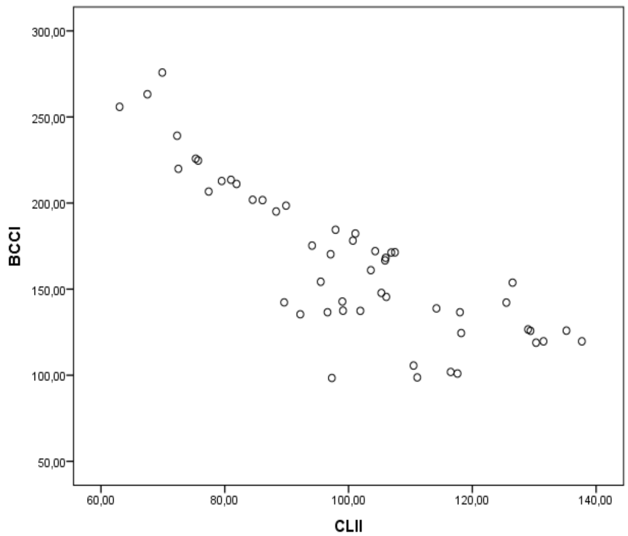


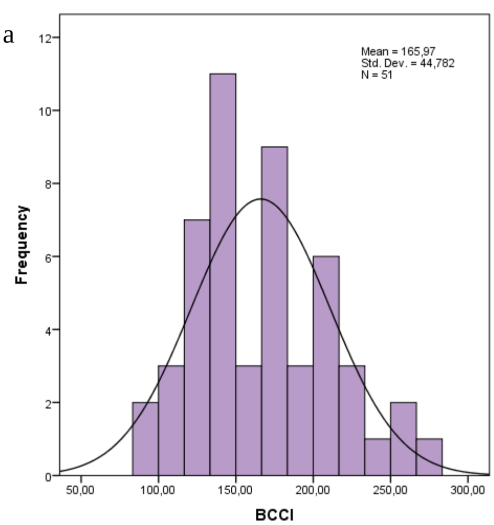
Fig 1. Scatter plot of the BCCI and (a) DPPI; (b) CPI; (c) CLII.

In order to select the applicable correlation coefficient, the Shapiro-Wilk tests were conducted to understand whether the variables distribute normally. The results of these tests are shown in Table 2. The results show that, the BCCI, DPPI and CLII are normally distributed at 0.05 significance level since their p-values are higher than 0.05. On the other hand, the p-value of the CPI (0.033) is lower than 0.05 which indicate that the CPI is not normally distributed. However, since the sample size (n=51) in this study is bigger than 30, it can be assumed that the distribution is normally distributed according to the Central Limit Theorem. The histograms of the BCCI, DPII, CPI and CLII with normal distribution curve are shown in Figure 2.

Table 2. The results of the Shapiro-Wilk tests.

	Statistic	df	Sig.
BCCI	0.959	51	0.074
DPPI	0.955	51	0.051
CPI	0.951	51	0.033
CLII	0.979	51	0.496

a



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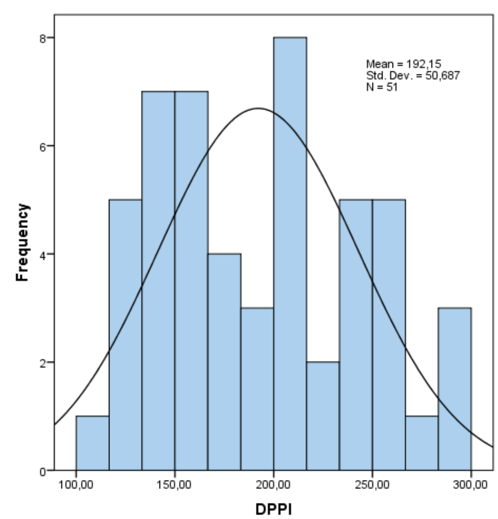

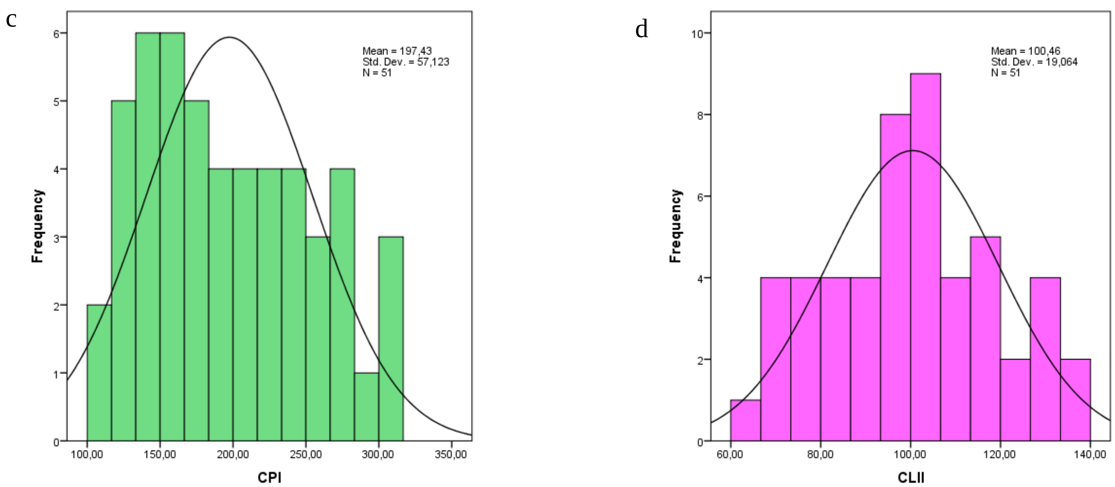

Fig. 2. The histogram with normality curve of (a) BCII; (b) DPII; (c) CPI; (d) CLII.

Since the variables are normally distributed, the Pearson correlation coefficients were calculated to understand the strength and the direction of the relationships between the BCII and three variables (DPPI, CPI and CLII). The Pearson correlation coefficients calculated at the 0.01 significance level are shown in Table 3.

Table 3. The Pearson correlation coefficients.

		DPPI	CPI	CLII
BCCI	**Pearson Correlation**	0.993	0.989	-0.831
	Sig (2-tailed)	*0.000*	*0.000*	*0.000*
	N	51	51	51

The results show that the calculated Pearson correlation coefficients are statistically significant since their significance levels are lower than the 0.01 significance level. Moreover, the results indicate that there is a positive correlation between the BCCI and two variables including the DPII and CPI (0.993>0; 0.989>0) whereas there is a negative correlation between the BCCI and CLII (-0.831<0). In other words, when there is an increase in the DPII and CPI, the BCII also increases whereas when there is an increase in the CLII, the BCII decreases. The results also show that the BCCI has a very strong correlation with the DPPI, CPI and CLII since the calculated Pearson correlation coefficients are higher than 0.8 [16]. However, the closer the value is to 1 or –1, the stronger the linear correlation. As a result, it can be said that relationship between the BCCI and DPPI is the strongest relationship (Table 4).

Table 4. Strength of relationships between the BCII and three variables

	Linear Correlation	
	Direction	**Strength**
BCCI vs DPPI	positive	very strong
BCCI vs CPI	positive	very strong
BCCI vs CLII	negative	very strong

5. Conclusion

As the BCCI is used in the cost estimation of buildings, it’s important to understand the influencing factors and the impact of input variations in the BCCI. This study aims at investigating whether the historical data of different economic variables is useful to investigate the variations in the BCCI. The results of this study indicated that the

BCCI has a very strong positive correlation with the DPPI and CPI. In other words, when there is an increase in the DPPI or CPI, BCCI also increases. Moreover the relationship between the BCCI and DPPI is the strongest relationship. On the other hand the BCCI has a very strong negative correlation with the CLII, which means that when there is an increase in the CLII, the BCCI also decreases. Future studies can extend the scope of this study by using more economical variables or construction indexes and also by predicting the future values of the BCCI using time series models.

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Using RFID's for Job-Site Productivity Evaluation of Labor and Crews

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Abstract

Radio frequency identification (RFID) provide unique identification of objects through non-contact scanning. RFID technology has developed to the point where the price point has made the technology pervasive for inventory control and management of commercial products. Inventory control and storage management is paramount within construction and RFID's provide a useful alternative to bar-codes and other inventory management approaches. RFID's have the additional benefit of providing short-range communication capabilities which could enhance security and theft prevention through 'geofencing' style control. Material and equipment management are natural applications for the technology. The question naturally arises as to the impact of RFID on labor management and how such technology could be used to improve job-site productivity. This has been explored through research performed on-site in the Middle East to track location of workers and to post-process information for productivity assessment. The results of the study will be presented, the advantages and disadvantages discussed, and future research directions proposed.

Keywords: construction; productivity; RFID

1. Introduction

Proficiency within a wide variety of tasks is required in order to deliver a construction project successfully: on-time, within budget, at the quality prescribe and in a safe manner. The construction management team must determine and define the methods and procedures necessary to assemble the components and to complete the project. The materials and/or components must be acquired and delivered to the installation location. Labor and equipment must be assembled and must be efficient and effective at performing the tasks required for installation. If the materials do not show up at the proper time, labor and equipment are unable to install and both costs and time increase. Likewise, if labor and equipment are not effective at installing or have diminished productivity, costs and time increase. These situations jeopardize the successful installation of a given item. If too many items have delays, the economic success of the project may be jeopardized and the project completion dates delayed. To avert this and ensure project success, the construction management team must ensure that the materials, labor and equipment are managed effectively.

Starting with the materials, it is easy to see that the construction management team must know where the materials are and must coordinate effectively to ensure that they get to the right place on the job-site at the right time. Coordinating the movement of the materials through the supply chain and/or on the job-site is the central purpose of a materials management system. Without an effective and proactive materials management approach, it would be difficult to ensure success in construction project delivery. The systems which have been used historically were heavily reliant upon paper-based tracking and reporting, which has now evolved to the use of bar-codes, RFID's and proactive notifications.

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Materials management and product supply-chain management are prototypical applications for RFID implementation. With RFID's, items can be tracked and traced as they progress through the supply chain to the consumer or point of installation. RFID's have also been proven to be effective for equipment management. This includes both large-scale equipment, such as backhoes, graders, etc., and small tools. For both materials and equipment, RFID's are proven technologies for tracking and for inventory management.

Of interest is the use of RFID's for productivity and for development of a system which provides support for project managers to identify and correct productivity issues early. This is a bit easy to see when looking at equipment management for large scale machinery which operates on a cycle. Placing RFID readers at points through the cycle can be a useful tool for productivity assessment of the process to determine times for loading, hauling, unloading and returning. Where deviations occur and are identified, corrective action can be taken efficiently and effectively. Small tools and hand-held power equipment are generally not used and evaluated on the basis of a cycle. For these tools, RFID's provide effective management information in terms of tracking, locating and associating the equipment with project personnel and/or job-site location.

For both the materials management and the equipment management applications, RFID's also provide information that can have positive impact on security and theft control, especially where controlled access to the site is possible. While productivity applications may be lacking, opportunities for use of RFID's can been seen and creative applications can readily be conceptualized if challenging the status quo.

Labor management on a construction site can also benefit through the use of RFID's. Employees can be 'clocked-in' when entering the job-site and their location on site partially determined, depending on the density of RFID readers positioned on site. This can replace more expensive finger-print sensors and increase the reliability of the information collected and maintained since it is not dependent on the action of the employee. It is also a more effective way to ensure proper access control in addition to tracking and employee management.

Where employees are working on cyclical tasks, such as delivering materials, labor productivity can be ascertained by tracking employees progress and timings through the cycle. This is also applicable for equipment operators, though that information becomes somewhat redundant with the equipment cycle data. The sensor, however, have no ability to recognized the tasks that are being performed at a given time. They simply recognize the location and transfer information that can then be acted upon using an if-this-then-that type of approach.

The question naturally arises as to whether the RFID systems can provide further information that would be useful for productivity assessment. This question was explored in by the authors through a small research project initiated in the Middle East with the intent of demonstrating proof of concept for wider implementation. The results and the background work performed to investigate the feasibility of the approach are presented herein. The paper begins with a definition of RFID's and a discussion of their uses and implementation within the marketplace. The goal is to explore the use of the technology as a tool for labor productivity and research efforts focusing on the use RFID's for productivity is discussed. This includes discussions of research for materials management, equipment management and labor management with the objective of culling useful information for productivity evaluation. The research discussion is followed by a summary of experiences with implementation of RFID on a high-rise commercial job-site in the Middle East. Advantages and limitations of the intended research activity is identified and unexpected difficulties with the labor workforce are discussed. The goal of the work was to provide proof of concept in order to extend and expand the research and a plan for this area is outlined prior to the discussion of conclusions.

2. What are RFID's, Where Are They Used, and How is the Technology Employed?

RFID stands for radio-frequency identification, which has become increasingly prevalent in commerce throughout the globe. An RFID tag enables storage of electronic information that can be associated with a given object, such as a piece of equipment or a product. Products and materials in construction may be discrete, such as a door or window. These items allowing individual tagging; however, other materials may be 'fluid' and unable to be tagged. Such materials, such as plastic concrete, can still be managed with RFID tags as long as there is a surrogate placement of RFID tags. This could include placement of the tag on a delivery ticket or on the delivery truck.

In most applications, the RFID tags are passive and receive power from the RFID reader when interrogated. Active, battery powered tags are available which provide greater range; however, they are more expensive and physically larger in size to accommodate the power source. Regardless of the tag technique used, RFID's provide the same benefit. Unlike bar-codes, RFID's do not require line of site or visual scanning in order to convey the information. Tags can replace the bar-code entirely; however, in most commercial applications of RFID's, bar codes are retained. The RFID tag provides a complement to the bar code, which provides redundancy and is retained as a back-up system.

RFID's are used in an extremely wide variety of applications including access management, toll collection, inventory tracking and tracking of items through logistical processes (such as luggage or packages), security of inventory, and timing of sports events. The technology has become ubiquitous within commerce and creative applications are emerging to use RFID's for a wide variety of additional purposes. This includes using RFID technology to:

- personalize advertisements based on smart-cards linked with facial recognition and social media integration,
- locate underground assets as part of an infrastructure management program.
- track, optimize and effectively bill for waste management,
- manage and support maintenance on commercial aircraft
- minimize traffic delays through intelligent transportation systems linked to toll collection systems, and,
- for micro-chipping of pets.

A study on the use of RFID technology specifically within a retail product supply chain identified the following primary applications, some of which are very applicable on a construction site. As identified by Liukkonen [1], these are as follows:

- "Warehouse inventory tracking and management
  - i.e. 'Manufacturing logistics'
  - Control of material flows
  - Management of picking, receiving, and shipping
- Process monitoring, management, and control
  - Tracking of WIP and assembly status during production
  - Quality control and process management on the job-shop level
- Tool management
  - Locating production tools using RFID
  - Supply chain management of manufacturing tools and instruments
  - Control of manufacturing robots and instruments
- Supply chain management
  - Distribution of information about the location of individual products progressing through the chain from manufacturers to selling companies and end-users
- Life cycle management
  - As above, but concerns the monitoring and management of entire life cycle." [1]

Construction certainly has supply chain concerns and the RFID's can be used for some of the same purposes employed in retail. In construction, the technology can be used for inventory control, to provide access control, tracking of items through the supply chain, to support billing and progress payments, and other applications. Construction, however, is a very unique industry and the implementation of these common applications is very different from retail applications in terms of the process. Opportunities for advancement specifically in the construction arena must also be considered, which has been explored through publication in the RFID Journal [1]. The article, which explored potential market applications for professionals focusing on the sensors, identified the following example uses for RFID technology in construction:

- To monitor equipment and products on the jobsite and to issue alerts of equipment and/or materials and products are not located in the proper areas. This was done to ensure that productivity and the schedule was controlled not to control theft as the site was in a remote area with little opportunity for theft.
- To ensure that tolls and equipment are tracked properly when checked out from storage and equipment sheds. This ensured effective equipment management.
- For inventory management on the site in order to decrease the amount of waste and loss generated.
- To track progress of delivery of large precast units and other modular construction assets.
- For workforce management by tracking the number of workers on the job and their identities automatically when entering and leaving the site.
- To enhance construction safety by identifying when workers were entering hazardous areas, such as high-stories with fall hazards or underground work.

A variety of creative uses for personnel tracking have been explored and associated commercial products developed. As an example, RFID can track smart-badges for employees entering buildings. With an RFID access control system in place, the sensors and the resulting information can be used for tracking emergency responses. This is particularly useful in hazard prone areas where earthquakes or fires may call for rapid evacuation. The system, if in place, could be used to ensure whether all employees were evacuated and arrived within assembly areas. Using this approach requires deliberate management of access control, by necessity, would require a holistic system requiring employees and building visitors/occupants to be 'badged' at all times. Such culture is commonplace in large organizations and governmental agencies. This application has significant benefit in the event of an emergency, such as an earthquake or fire. [2]

A variety of RFID-based systems are being marketed for personnel tracking, for hospital patient tracking, and for child care/elder care management [3]. The author has observed the application of such systems through RFID-tagged wristbands which then permit care workers to identify where loved-ones are located within a given facility. Systems observed do not provide specific locations like a GPS receiver but rather identify rooms and areas where the RFID-wristbands were last located. Nevertheless, it provides very useful information for management of a particular program, such as nurseries.

3. Research in RFID Applications in Construction for Productivity

In a survey of sensor applications in construction performed by Zhang, Cao and Zhao, approximately 90 recent research studies using sensors and sensor networks for construction safety were identified. Of these, one-third of the studies (29 of 91) identified were conducted using RFID's for construction safety management [4]. Other sensor technologies explored for included wireless sensor networks, vision-based sensing, and ultra-wide band (UWB) systems, wireless LAN's, and select proprietary systems. GPS was not pervasive and only used in 6 of the 91 studies identified. This makes sense as GPS is frequently inaccessible when placed in an indoor environment. Safety management research topics employed RFID included research into various developments of integrated safety management systems and accident forewarning systems [4]. Regardless of the system used, the types of data necessary must further be considered. For instance, in order to determine whether an employee is near a particular hazard and is in danger, a level of precision in locating the employee is required. The RFID's must track the position of the tag/employee instead of just a broadly defined location.

RFID's have the capability to track positions of RFID tags with varying accuracy, depending on the location and the arrangement of the readers in relation to the tags. Research done on using RFID's for locating objects on construction sites showed 3.7-meter positional error [4,5,6]. Better results were obtained in other studies which demonstrated a 1.3-meter average positional error [7]. It was recognized that more accuracy could obtained with the use of more advanced algorithms [8]. In work done by Lee, Lee and Park [9], sub-meter locational accuracy was obtained using RFID's. On construction sites, obtaining this level of precision consistently could be tricky due the under-construction nature of the environment and the potential for interference with signals from site objects. Furthermore, the cost effectiveness of employing RFID readers is questionable when considering the large number that would be required to cover the entire construction site [4]. The use case explored in practice must be carefully designed so that reliable results are obtained with the practicable precision of the sensor network.

In evaluating productivity applications of RFID's papers tend to focus on two different areas: construction equipment [11] and construction materials/inventory management where numerous research activity is performed and case studies abound. Research activities also extend materials management beyond the site where items can be tracked through the supply chain. In these applications, it is possible for project management personnel, if given access to the information, to identify the status of deliveries and to get real-time updates of delivery times. This provides useful information into the decision-making process.

Interesting studies using RFID's for a variety of useful applications were identified in the review of available literature. Studies identified includes using RFID-based systems for inventory management in emergency relief operations [12], to managing shared inventory in steel yards [13], and to track large-scale products with multiple delivery challenges in precast plants [14]. Interesting work has also been performed using drones for material tracking on construction sites [15].

In examining the research, it is clear that there are some limitations with RFID's for productivity evaluation and for safety evaluation. The tag/reader combination can isolate positions and transmit information about the worker; however, it does not give insight into the worker activity. To evaluate the behavior of the workforce, an alternative approach must be coupled with RFID's. Zhang, et. al., explored the use of other sensor systems but these approaches only impacted the ability to locate a tag or employee. The systems do not have the capability to determine the activity being performed by the employee, whom may be productive or unproductive at various times throughout the day. An alternative approach is required to capture this information. One of the most promising techniques identified in the literature involves automated or 'smart' imagery and video processing. Significant research is on-going in this area for construction performance monitoring [16]. The images, captured using photographs, time-lapse or video live-stream, are processed using algorithms and techniques to recognize both the worker and to evaluate the behavior. The algorithms to facilitate this process are rapidly advancing and imagery based approaches show significant promise. Researchers focusing on development of imagery-based systems recognized that "the future of intelligent construction monitory can rely on multiple types of sensors or sensor networks," including RFID's to, "compensate [for] the disadvantages of visual sensors and provide more types of information" [16]. Benefits for these types an integrated approaches are clear for productivity but can also have significant application throughout the construction enterprise.

4. The Use of RFID's for Productivity: Exploring the Approach in Commercial Construction

To explore how RFID's could be used for labor productivity, a test case was devised using RFID's for implementation on a commercial construction site in the Middle East. RFID tags were placed on worker hardhats and readers were implemented within a limited area of an active construction site. The readers permitted tracking of when workers entered the area of interest on the job-site. Only the skilled and unskilled labor on the finishing crew were fitted with RFID tags.

It was recognized that locating a worker does not give an indication of the work being performed. Nevertheless, it was expected that RFID incorporation would provide easily obtained data that provides benefit for productivity evaluation. The research was designed so that benefits obtained on a small scale would provide proof of concept as a value-added technique. A more substantial research project would then follow with the approach employed for a larger segment of the workforce. The ultimate goal would be for eventual implementation across site for all employees. As technology advances, other features could be added moving towards a tool permitting near real-time evaluation. In other words, the objective was to start small, demonstrate effectiveness and subsequently expand until a difference could be made across the site and company.

In this study, the system was designed to get an indication of the time that workers spent in a given area. This would then be correlated to the amount of work performed in the area. The specific area chosen for evaluation was limited by the work being performed and access granted by project management team. Constructed masonry partition walls were completed and the labor and crews considered in the study only worked on finishing of the walls with a cementitious skim coat. There were no known conflicts in schedule between trades and no space limitations. No special considerations were required for implementation of the study other than fitting of tags and readers and access to daily reports.

There were significant limitations with the area permitted for the study. The overall site involved the construction of a large commercial tower and a portion of one floor was made available for the study. The planned work was scheduled for 3 days and there was limited opportunity for changing the level of effort or changing the activities and items performed by the crews.

The work being evaluated only involved a small number of workers from part of a large work-force. It was not practical to fit all construction workers with RFID tags as the time availability was limited and the data was expected to provide proof of concept for further study. Workers were informed of the study was being performed and that RFID tags were being used. The research team did not anticipate any issues with this approach since all workers on this site were accustomed to using fingerprint sensors for access tracking and control. When workers passed by a fingerprint sensor on the job-site they were obliged to check-in, regardless of the trade. This was used for monitoring of and accounting for the workers' time. The finger-print data was not used for productivity assessment and was not accessible by the research team. Nevertheless, it was presumed that the laborers would be accustomed to tracking and that there would not be any issue with implementing the RFID's.

A limited number of RFID readers were employed. The readers tracked when workers entered or exited the study area. Entering or exiting was determined on the basis of the time-stamp and for continuing research efforts, an enhanced system would need to be implemented in order to isolate the direction of the worker travel. The data would show progress under the reader but would not indicate whether the worker was entering or exiting the area of interest. This was inferred by the researchers based on the timings and the daily break schedules. In the future, the sensor network could easily be modified to evaluate entrance versus exit automatically without manual input.

When implementing the systems, it was expected that work would progress unimpeded by the study. This assumption was not valid. Laborers on the affected crews did not welcome the RFID's and either removed them from the hat, cut and damaged them, or used other workers' hardhats. These workers objected to being tracked and this was an understandable recourse. As such, reliable information was not obtained during the initial day of the study. No problems were experienced with the readers, which were largely ignored. Further complications came from the workforce that were not chosen to be part of the study, whom resented that they were not chosen for a special type of task. The resulting pressure on the crew by their co-workers further exacerbated the difficulty with implementing the tags. Despite discussion with foremen and superintendents, worker distrust persisted through the course of the study and limited information was obtained. The information could thus not be correlated with the work performed.

The resistance by the workforce was unexpected by the research team but not unprecedented. It is understood that early implementation of camera surveillance on construction sites had received resistance from the workforce and may still be a sensitive issue among unionized labor. Since the study, efforts were undertaken by the supervisory staff on the site to ensure that workers would not damage the RFID's tags. This was done independent of the study as the workforce is no longer performing tasks within the study area and RFID readers have been removed. Site personnel indicated that it took about 2 weeks for the labor to progress without care of the RFID tags. It is unknown whether similar problems with labor acceptance will occur in future studies.

For future implementations within this marketplace, care must be taken to avoid the problems resulting from labor resistance to being singled-out and having RFID tags. There are many different ways that this could be addressed. In a large-scale implementation, RFID tags could be provided for all hard-hats either as a specific tag akin to the type used for product theft control. Alternatively, RFID tags could be integrated within hard-hat stickers or within clothing worn by workers, such as safety-vests or coveralls. This will become easier as miniaturization becomes more prevalent within the marketplace.

5. Summary, Conclusion and Future Directions

This research study was initiated to develop simple, low-cost approaches for improving productivity in commercial construction in the Middle East. The concept initiated involved installing RFID readers within a controlled area on an active construction job-site and to track RFID tags placed on finishing crew skilled and unskilled laborers. The study was intended to demonstrate viability of the approach through a short-term, low-impact implementation. It was hoped that positive results would then lead to further, more extensive studies over the job-site.

The study began by exploring market-accessible products and past implementations in the Middle East and abroad. Commercial products were available for personnel tracking but low-cost RFID systems available within the marketplace were used for proof of concept. For future study and more extensive research, commercial systems available would have benefit due to the value-added capabilities of the software and the approaches to information management. Research publications were also examined and a number of interesting studies were identified. Studies focused on locational capabilities of the sensors, the use of RFID's for inventory management of materials, supply chain issues and optimization with RFID's, equipment management and productivity, safety analysis and other areas. Few studies were found that were coupling productivity evaluation with RFID's. Notable studies in this area were employing imagery and videography which show significant promise, especially when coupled with sensor systems.

There were unexpected difficulties with the workforce when trying to implement the research. These could not be overcome given the small scale of the research and the limited time window for the research activities. As a result, proof of concept will have to be demonstrated in a different environment. Plans are being formulated to look at RFID within labor training centers established for indoctrination of new employees to the systems employed at the site. The difficulty with this approach is that often it may be difficult to correlate workers receiving training with a reasonable level of productivity. Nevertheless, proof of concept will be easier within a controlled environment and will also help with making employees accustomed to the RFID tags. The researcher team is confident that the approach can be demonstrated as effective within this environment.

It is further recognized that the use of RFID tags is going to have limitations when it comes to productivity assessment. Location can be determined but a sensor-only implementation cannot ascertain whether employees are actively engaged in productive work, supportive tasks or idle. Only macro-level productivity can be obtained by looking at the time in proximity to the work task and the overall quantity completed within a given period of time. This information would provide incremental advancement for evaluation purposes but more data would be desired to closer to real-time feedback. It is expected that coupling of the RFID or other sensor approaches with video and imagery will provide this capability in the future.

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A Framework for Modelling Masonry Construction Using Hybrid Simulation Approaches

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Abstract

Labour is a crucial resource for construction projects. More risks are associated with this than with other resources, such as materials and equipment. Contractors need tools to make more precise estimations concerning labour productivity that will allow them to minimise these risks and manage labour resources in the most efficient way possible. To achieve this, use can be made of construction simulation techniques, however, depending on the complexity of the problem, applying a single simulation approach might not be enough to appropriately model construction. Hybrid simulation approaches seem to be suitable because they combine the advantages of their components to reflect the dynamic nature of construction processes better and consider the number of uncertainties. Hybrid approaches can combine traditional discrete-event simulation (DES), agent-based modelling (ABM) or system dynamics (SD) with each other or with, for example, fuzzy logic (FL) to better capture the factors influencing productivity. To address these issues, a framework for modelling a masonry construction process that uses hybrid simulation is presented. Because masonry works are one of the most labour-intensive construction processes, and skilled labour resources are scarce, the use of such a framework would help contractors to make more realistic schedules based on accurate labour productivity estimation; thus, enabling them to utilise their resources more efficiently.

Keywords: agent-based modelling, discrete-event simulation, fuzzy logic, hybrid simulation, masonry, productivity, scheduling, system dynamics.

1. Introduction

Construction project success is usually measured by the triumvirate constructs of cost, time and quality, which directly affect labour productivity. Even though there have been efforts to use prefabricated elements, construction projects can still be considered labour-intensive works. As a result, forming active crews is critical to successful projects. Before construction, to make cost calculations and schedules reflect reality, reasonable estimates of labour productivity are essential.

Construction simulation, which has evolved since the development of computers, is a useful method for modelling ‘workflow’ that provides professionals with productivity data. Gordon [1] suggested a general-purpose simulation program to solve problems arising from telecommunications to manufacturing. Teicholz’s [2] link-node model that was developed in 1963 could be considered the forerunner of construction simulation. Since then several different approaches have been proposed.

Most of the existing literature on construction simulation introduces earthworks (see, for example, AbouRizk and Halpin [3], Alzraiee, Zayed and Moselhi [4], Lorterapong and Moselhi [5]), reinforced concrete works (see, for example, Khanzadi et al. [6], Moradi, Nasirzadeh and Golkhoo [7], Nojedehi and Nasirzadeh [8]) or civil engineering works (see, for example, AbouRizk and Sawhney [9], AbouRizk [10], Robinson Fayek and Oduba [11]) as case studies, which are mostly machine-driven works. However, it is arguably more important to simulate labour-driven works as labour resources tend to be scarcer (especially skilled) and more risks are involved with them than with equipment or

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materials. The focus of the paper will be concentrated on masonry construction, which is a labour-intensive work, and a traditional element of a construction project. Accepting that some materials have changed over the centuries, masonry remains a vital part of many projects, such as housing. Furthermore, the possible application of a developed framework for other labour-driven works needs to be considered in the future.

The remainder of this paper firstly introduces the basic simulation approaches, then overviews hybrid simulation approaches. Next, a framework is presented for the utilisation of simulation in case of masonry construction projects. Finally, the conclusions are drawn, and the direction of future research in the topic is set.

2. Basic simulation approaches

One of the essential simulation approaches is a discrete-event simulation (DES), which focuses on, and models the process itself. The first notable construction simulation tool using DES was Halpin's CYCLONE (CYCLic Operations Network) in 1973, which was intended to be a general-purpose simulation system [2]. Martinez [12] has described a methodology for conducting DES that draws attention to the possible problems, which could put the model's validity in jeopardy [12]. Activity durations in DES models can be described by probability distribution functions like the ones used in Program Evaluation and Review Technique (PERT). Law [13] attempted to collect all the available functions (ranging from uniform to Weibull, including the Johnson and Pearson systems) with their properties and explained their usage in case of simulations. AbouRizk and Halpin [3] suggested that flexible functions are needed due to the 'diversified nature of construction duration data' [3, p. 537], and advised the use of the beta function because of its familiarity in the construction field. Hajdu and Bokor [14] argued that a careful three-point estimation is more important than the type of distribution function selected. Monte Carlo simulations performed on hypothetical and real-life projects showed that a 10% difference in the three-point estimation causes greater deviations than the chosen distributions [14].

Another simulation approach is system dynamics (SD), which was developed by Forrester [15] at the beginning of the 1960s. SD is a top-down method concentrating on the various influencing factors and the relationships among them showing the entire system's workings with feedback loops [15]. SD can be used for both qualitative and quantitative modelling: the former focuses on creating a causal loop diagram, while the latter determines stocks and flows and expresses the links with equations [16]. Mawdesley and Al-Jibouri [17] used SD to determine which areas should be improved by the management to increase productivity. The model contained planning, control, motivation, safety and disruptions as the most significant factors. Several strategies were tested, and it was found that the first two need the management's particular attention [17].

In contrast to SD, agent-based modelling (ABM) has a bottom-up approach: the system's behaviour emerges from how heterogenous agents interact with each other and their environment based on the defined rules. Siebers et al. [18] argued that ABM had an advantage over DES, in cases where the focus is not on the process but on how the individual agents, who can learn and adapt, can affect the system. Son, Rojas and Shin [19] emphasised similar positive properties through examples of project teams in large-scale construction projects. They recommended ABM for modelling, for instance, the international construction market with countries and firms as agents [19]. Sawhney et al. [20] advised the usage of ABM to increase construction safety on site by modelling the construction environment, workers with various tolerance towards risk (agents) and safety management practices. Watkins et al. [21] used ABM to determine how site congestion affects productivity; two agent types were defined: workers (with variables such as skill level) and activities [21]. Dabirian, Khanzadi and Moussazadeh [22] applied the same two agents in order to estimate labour costs better. Hsu et al. [23] applied ABM to assess team member selection models. In their research, the agents were the workers with attributes such as experience and skills. It was concluded that interdependence-based selection is preferable to skill-based assignment [23].

3. Hybrid simulation approaches

The approaches described above are often used individually but can also be applied in combination. A benefit of the combined approach is to use the various advantages of each method and to balance its shortcomings. The most suitable approach should be selected for each component of the model and, depending on the question that needs to be answered, the combination will provide a replica of reality [24] and [25].

Different names exist for these combined approaches, including: 'hybrid', 'multi-method', and 'multi-paradigm' [26]. Mosterman [27] defined the composite of discrete and continuous simulation as 'hybrid simulation'. Balaban, Hester and Diallo [28] argued that ABM might not be considered a paradigm; hence, those approaches where ABM is paired with another method may not be called multi-paradigm. According to them [28], there is also a distinction between mixed/hybrid and multi-methods. Both Mustafee et al. [26] and Balaban, Hester and Diallo [28] agree that proper definitions are needed.

Furthermore, the three basic simulation approaches can be mixed with methods, such as neural networks (NN) or fuzzy logic (FL) [28]. These could also be considered hybrid approaches [8] and [10].

However, in this paper, the term ‘hybrid simulation’ refers to any method where a basic simulation approach is combined with either another basic simulation approach or fuzzy logic.

3.1. The possible combinations of the basic simulation approaches

Fahrland [29] suggested the combination of DES and SD to create improved, more realistic, more efficient models. According to him [29], there are many possible applications for these hybrids from aerospace missions to nuclear power plant start-ups. While DES concentrates on the process, dealing with issues on the operational level, SD is suitable for modelling on the strategic level; thus, complementing each other [30]. With the help of combined DES-SD systems, it is possible to coordinate managerial and operational decisions to increase productivity [30] and [31]. In the interest of obtaining more realistic project duration data, Alzraiee, Zayed and Moselhi [32] complemented DES with SD as well. The latter was used to take the affecting factors (for instance, weather and overtime) into consideration.

DES can also be combined with ABM. In operational research, instead of pure ABM, mostly a hybrid model is used where the entities of the DES are active, ABM agents [18]. The same is true in healthcare, where simple DES models are rare, and instead, ABM is used within DES [26] (see, for example, Borshchev [24]).

Lättilä, Hilletofth and Lin [33] urged that researchers should combine SD with ABM to combine the positive features of both approaches. They also mentioned that both systems could be used to model the same problem and then the results could be compared [33]. Nasirzadeh, Khanzadi and Mir [34] proposed an integrated SD-ABM simulation approach to model construction workers’ safety behaviour and its effect on the project duration. In the ABM model, contractors were chosen as agents, and each of them had their SD models showing the influencing factors. There was constant information flow between the models [34]. Khanzadi et al. [6] also used an integrated SD-ABM simulation approach to see how site congestion affects productivity.

Borshchev [24] provided an example for combining all three basic approaches where DES is used to model the supply chain process, SD describes the market, and the participants are represented by agents.

3.2. Using fuzzy logic

Mixing the basic approaches with each other is not the only option to improve the models. Another possibility is to use, for example, fuzzy logic (FL). Zadeh [35] stated that the nature of the problem determines whether probability theory, fuzzy logic (FL) or a combination of these is required for the solution. FL is preferred in cases of uncertainty and imprecise data, which is ‘nonstatistical in nature’ [35, p. 421]. Ayyub and Haldar [36] proposed the use of FL for including uncertainties given in linguistic terms in project schedules. Weather conditions and the experience of the workers were arbitrarily selected as factors in their example. The modified activity durations were calculated based on the frequency of occurrence of the factors, their negative effects on the duration and the membership functions [36]. Robinson Fayek and Oduba [11] analysed two activities from a real-life industrial construction project with the help of FL, collected the factors affecting productivity (in two sub-models to decrease the size of the model) and the related ‘if-then’ rules. Triangular and trapezoidal membership functions were used, complete with experts’ estimates for the endpoints. Then, these results were compared to actual project data [11]. With the number of factors increasing, the amount of rules grows exponentially; therefore, Shaheen, Robinson Fayek and Abourizk [37] proposed to gather the related factors under blocks. Lorterapong and Moselhi [5] introduced FNET (fuzzy network scheduling), in case there is no available historical data or fair expert estimate. The proposed method produces more realistic results in the backward pass, affecting criticality [5].

Raoufi, Seresht and Robinson Fayek [38] provided an extensive overview of the combinations of FL with DES, SD and ABM in construction, showing the advantages of integrating FL into the basic approaches and giving advice on the appropriate choice of a hybrid technique.

AbouRizk and Sawhney [9] developed SIDES (subjective and interactive duration estimation system) with the aim of determining more realistic beta distribution functions for activity durations in DES with the help of FL. The users of the application had to define the two endpoints of the function; however, fitting was based on the selected influencing factors expressed in linguistic terms [9]. Zhang, Tam and Li [39] also suggest the application of FL in DES in cases when there is no field data to use. Even when there is, FL could be used to incorporate 'vagueness, imprecision and subjectivity' [39, p. 727].

Khanzadi, Nasirzadeh and Alipour [40] integrated FL into SD to determine the ideal concession period in case of build-operate-transfer projects. The influencing factors with their causal loops made up the SD module, while the magnitude of the factors was calculated by FL [40]. De Salles, Gonçalves Neto and Marujo [41] applied the same combination to evaluate business decision policies. The critical factors influencing the system were modelled in SD, while FL translated the policies given in linguistic terms into the SD model [41]. Nojedehi and Nasirzadeh [8] also combined SD with FL, while the former part of the model contained the most important factors influencing labour productivity; the latter component was used to express the effect of those factors that could not have been done with crisp values. With the help of the model, possible solutions for improving productivity were tested to contribute to better managerial decisions [8].

Raoufi and Robinson Fayek [42] combined FL with ABM to investigate how crew performance is affected by the workers' personality, their interactions with each other and their environment. Two layers of agents were defined: workers and crews. The 'what-if' rules of agent behaviour were expressed in linguistic terms, which were translated using FL [42].

3.3. The structure of hybrid simulation models

Selecting which approaches will make up the hybrid to solve a given problem is only the first step. Next, the structure must be determined. There are numerous options that explain how the methods could be combined. Borshchev [24] described the six most frequently used variations and provided examples for all of them. These are [24]:

- agents in an SD environment
- agents interacting with a DES model
- DES model linked to an SD model
- SD inside agents
- DES inside agents
- agents as entities in a DES model

Moradi, Nasirzadeh and Golkhoo [7] defined three possible ways the DES and SD models could be linked. First is the hierarchical format, which could either be SD- or DES-dominant. In this case, there is a vertical interaction between the strategic (SD) and operational (DES) models. The second one is the phase-to-phase format, where the two models run in separate phases. The third type is the integrated format, which allows constant bidirectional interactions [7].
Alvanchi, Lee and AbouRizk [31] also identified three structures of DES-SD hybrid models similar to the ones mentioned above [7]. These are the DES-dominant, SD-dominant and parallel modelling. In the case of the first two, the direction of the interaction is towards the dominant part, while in parallel models, the interaction is bidirectional.

Swinerd and McNaught [43] defined three classes for SD-ABM hybrid simulation. In the case of the integrated simulation, there is continuous feedback both ways between the two modules. Sequential simulation means that first, the SD module runs, and its output becomes the input for the ABM module or vice versa. The third class is interfaced hybrid design, where the modules run parallel and their outputs are combined [43].

3.4. Interface variables in the hybrid simulation

After the most suitable structure is selected, the interaction points between the components need to be defined. These interface variables are the ones that may affect the variables in the other component. According to Alvanchi, Lee and AbouRizk [31], there are five types of interactions:

- in case of one discrete and one continuous variable
  - a discrete change in the discrete variable causes a discrete change in the continuous one
  - a discrete change in the discrete variable causes a change in the functional description of the continuous one
  - a continuous change in the continuous variable causes a discrete change in the discrete one
- in case of two continuous variables
  - a continuous change in one continuous variable causes a continuous change in the other
- in case of two discrete variables
  - a discrete change in one discrete variable causes a discrete change in the other

4. Simulation framework

The framework for construction simulation can be seen in Figure 1. The first step in the process is to analyse the problem at hand. Based on whether a simple or a complicated question needs to be answered, or whether the part of reality to be modelled is simple or complex, the left or the right path should be chosen respectively. The next step is to select the most appropriate simulation approach. The choice could be made based on the purpose of the investigation and the required level of abstraction. The basic approaches provide different levels of abstraction. If the focus is on the process itself, DES might be the most suitable approach, as it could be used on the operational level. It provides information on activity and project durations and resources. In DES, the workflow of the masonry process needs to be modelled. For the construction masonry unit, the description of the workflow could be found in Florez and Castro-Lacouture's work [44], whereas Dawood, Hobbs and Fanning [45] provide the same for brickwork. SD concentrates on causal relationships on a macro level and tracks the changes of the continuous variables. In the case of masonry, it could be used, for example, to include the factors influencing labour productivity. ABM may be applied at all levels of abstraction. By defining the agents with their attributes and rules of behaviour, the workings of the global system are revealed. The agents, for instance, could be masons and labourers working on a project. The most critical variables concerning the workers are described in Florez's work [46]. The different wall sections could also be agents. Florez [46] and Thomas and Završki [47] provide possible classifications for walls in masonry construction. FL is useful in case the variables are subjective and could not be easily expressed with crisp values.

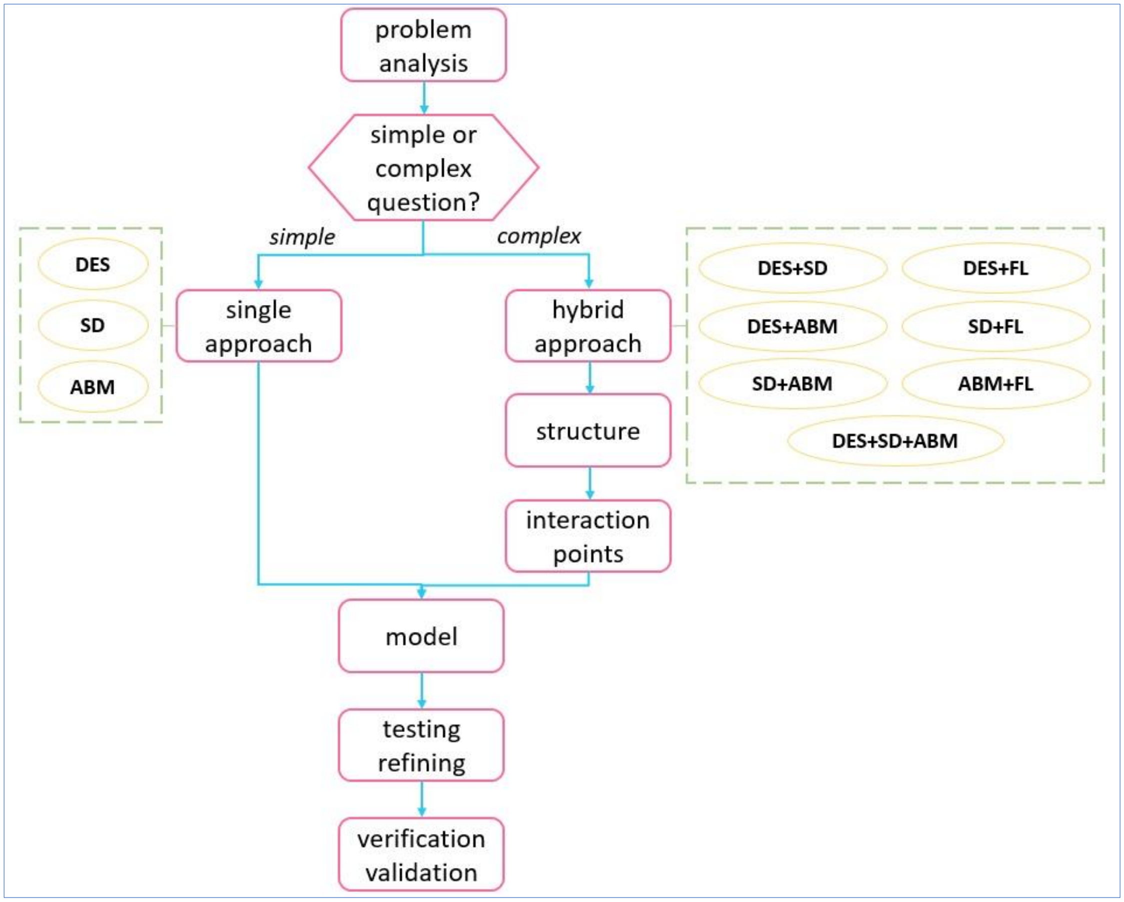

Figure 1. Construction simulation framework

If a hybrid solution seems appropriate, after choosing the most suitable approach, the structure must be determined. It could be one of the following:

- integrated: the interaction between the components is bidirectional and continuous
- dominant: one approach is more dominant than the other, and this determines the direction of the interaction, which will be towards the more dominant component
- parallel: the components are running simultaneously, and their outputs are combined

The next step in this branch is to define the interface variables described in section 3.4.

Based on the selected simulation approach, its structure and interaction points, if applicable, and the required input data, the simulation model could be produced. Afterwards, this needs to be tested and refined.
The ready model must be checked as well. Verification confirms that the model is a correct reflection of reality, whereas validation is performed to show that the model's accuracy is adequate for the simulation problem. Verification and validation, in fact, do not only happen at the end, but they are performed after every step in the model development process [48].

5. Conclusion

Construction simulation is a useful tool, which replicates reality; thus, providing valuable information on construction works. It could be applied to gain better productivity estimates to make more realistic schedules and cost calculations.

This paper explained a framework for construction simulation. Since construction projects are complex, and many uncertainties are involved, probably the most suitable simulation approaches could be found among hybrid simulation solutions. These combine the advantages of the selected techniques in order to better model reality.

Empirical research is needed to test the framework by using real-life case studies of masonry projects. It also must be checked whether specific approaches and structures are better suited for modelling masonry works than others. Furthermore, it must be investigated whether the system could be used in case of other labour-intensive works.

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A simulation-based approach for optimal construction planning and scheduling

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Abstract

Project schedules in construction are responsible for an efficient deployment of resources on the job-site and for the overall efficiency of work progress. Current approaches too often lead towards sub-optimal work plans or, sometimes, even scarce productivity. For that reason, a lot of research was devoted to the development of automated scheduling tools, which can provide optimal solutions while requiring reasonable computational effort. As a consequence, planners can save their time and involved resources can benefit from the efficient organization of work packages and tasks. However, automation in construction scheduling is a tough challenge, because it requires to generate and optimize multi-objective problems, which usually include several parameters. In addition, deviations from what expected is quite frequent, and these algorithms should be able to quickly revise the previous plan, in fact performing dynamic planning. Hence, this paper presents an agent-based approach, which can be integrated in a BIM-based platform to perform automated scheduling of construction works. The BIM component can provide instant access to relevant information, which must be integrated with some user defined inputs, in order to feed the optimization algorithm. This algorithm was based on the multiple ant colony system for vehicle routing problems with time windows, because it can handle several resources travelling through many locations, each one performing its task, even in the presence of time constraints. The optimization was performed with respect to both overall makespan and total costs. An application to the case of bored piles execution will be presented in this paper.

Keywords: construction planning; scheduling automation; agent-based simulation.

1. Introduction

Project schedules in construction projects help project management teams handle interrelated critical aspects of management, such as time, cost, resources. It requires availability of information both at the pre-execution stage and during execution. The standard construction practice is commonly done applying diagram methods to sequence activities that are based on work packages defined according to a work-breakdown-structure. In this phase, the planner's background and experience play a vital role in the creation of a construction schedule, because she/he is in charge of assuring consistency with the scope, plan efficiency and proper deployment of resources. Then, progress management usually involves deviation analyses between the actual progress and the initial plan that is constantly being updated and revised. The often scarce communication and the absence of automation requires the adoption of standard methods, such as face-to-face meetings and paperwork. This approach has been identified as an inhibitor to increasing productivity and a frequent source of miscommunication and rework [1]. To solve the problem of insufficient information and sub-optimal planning, researchers turned towards automating the process of generating schedules. Research has been carried out through the past decades in several fields, where automated tools demonstrated their ability to provide a variety of advantages, such as quickly generation and updating of schedules, optimization of project resource allocation and levelling, of the makespan and/or total costs.

However, there are several research challenges that are still open. In this paper, we will mainly focus on computational tools and on information handling. As far as computation is concerned, in the past decades a number of solutions were suggested, ranging from case-based and knowledge-based reasoning to model-based simulation,

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until the latest approaches inspired from artificial intelligence [1]. More recently, thanks to the advent of powerful computational tools, the potential of agent-based simulation was highlighted, and first applications in the field of optimal planning were produced. This approach manages to incorporate the inherent variability that arises from the independent construction subjects' behaviour as they interact on a construction site [2]. In fact, multi-agent simulation is suitable for modelling resources' behaviour and interactions in complex settings, like in construction. These models are capable of specifying the characteristic of trade crews, their work methods, the amount of work, workspaces and dependencies between tasks. As a result, simulations encapsulate both variability and uncertainty of the construction workflow [3].

The next section 2 of this paper reports the relevant background in the field, section 3 concerns a new algorithm for agent-based simulation, section 4 first suggests an overall framework for automated planning of construction schedules, then details about one scenario where it was implemented, finally it discusses its main findings. Conclusions and references sections close this paper.

2. Scientific Background

Automation in scheduling has been studied mainly in the last three decades and several approaches were experimented [1]. Cased-based reasoning (CB) is able to exploit the specific knowledge of formerly practiced situations and compares present problems with an earlier situation, which is then used to solve and explain the new problem [4]. Similarly, knowledge-based reasoning integrates knowledge from several sources (e.g. construction rules, basic physics etc..) for the purpose of generating schedules, even retaining learned experience. Genetic algorithms (GA) is an optimization tool that uses a heuristic search which mimics the natural evolutionary process. Using a mathematically defined fitness function as the objective function, the initial randomly generated genomes can evolve into optimized solutions for a given problem [5]. An expert system, which belongs to the artificial intelligence tools, is defined as a computer based algorithm that imitates human decision-making skills. Expert systems are designed mainly using if-then structures instead of regular practical codes. Neural networks are inspired by the brain of animals and are able to perform pattern recognition using "all-or-none" (i.e. a type of binary language) rule of the nerves. Several calculators are known, e.g. the "Hebb's rule". They need to perform optimization relying on a huge database, so their learning process must be fed by thousands of records. Model-based systems use formalized construction method models to perform the scheduling. These methods usually decompose higher level activities of the schedule into lower level activities to ease the linking of the schedule with diverse level of details.

However, none of these approaches can tackle all the relevant aspects of the scheduling problem. Indeed, case-based and knowledge-based are good at identifying tasks and sequencing them [4]; although genetic algorithms is known as a meta-heuristic optimization method that is mainly suitable for solving multi-objective problems [5], they were applied in scheduling mainly to optimize resource utilization and perform resource levelling to come up with better project schedules compared to heuristic methods [1, 6]; expert systems provided an ample flexibility of applications, but their development procedure is not standardized, yet, and relies on the experience and judgement of the researcher [1]; neural networks, besides requiring a huge dataset as previous knowledge, they were shown to be a powerful tool for dealing with some specific scheduling problems (e.g. job-shop scheduling, single-machine scheduling, timetable scheduling), it was not used for construction sequencing and scheduling [7]; model-based approaches requires a great effort in the development of rules (e.g. spatial reasoning) for automating, which some authors tried to simplify through the use of templates stored as a knowledge base [8]. As a result, one of the most important gaps to be addressed is the development of a hybrid approach that could address multiple objectives associated with scheduling [1].

Another important challenge is the development of adaptive algorithms. In fact, project planning is usually done at different levels. While a master schedule provides a global view of project milestones and the overall execution strategy, it must be always specified by a short-term schedule, which is a more detailed plan listing work to be done within a relatively short time window based on the most up-to-date site conditions and performance [9]. In the last planner system this second level is called look-ahead schedule. But the construction site is not stationary, and the plan must react to system changes on a real-time or near-real-time basis. So, when it is generated by a simulation model, it requires that such a model is able to capture site condition changes constantly and be updated accordingly so that the changes and their impacts can be evaluated in a timely manner [9]. In other words, adaptive framework must include real-time data acquisition modules, process interpretation modules, adaptive modelling and optimization algorithms. The long term goal of the adaptive modelling component is to streamline the model-updating procedure by taking advantage of inputs from the data acquisition and the process knowledgebase components. For example, real-time and most-recent values of an activity duration can detect changes in the duration pattern based on past measurements.

Further automation can be exploited in this process if a BIM repository is used as the archive of all the information required by the optimization algorithms to perform its estimations. To date, BIM was mainly used to generate quantity take-offs, 4D scheduling and building simulations. However, even the generation of construction schedules can retrieve data (e.g. spatial, geometric, quantity, relationships and material set of information) from what is stored in BIM models [10]. This approach would achieve significant time reductions in scheduling, compared to the traditional manual methods.

For the reasons stated above, in this paper we highlight that automated scheduling can take advantage of BIM-based structured information [10]. Then, an algorithm based on multi agent-based simulation will be suggested and its performances analysed, showing that it is able to imitate real world process of systems, where the global behaviour emerges as a result of interactions of single agents [11]. Agents can be active, proactive, autonomous, cooperative, adaptive and mobile. They interact to reach a global objective. This tool allows us to evolve from single-objective optimization towards a multi-objective optimization problem based on ant-colony simulation. In this approach, every objective can be optimized by a different colony, that is cooperating and contributing to the whole process. In addition, the framework proposed in this paper was designed so as to be capable of continuously re-planning the schedule as a result from unexpected occurrences, in fact performing dynamic and adaptive scheduling. In the implementation, several scenarios will be proposed in order to show the sensitivity of the algorithm to several inputs, such as the ratio between direct and indirect costs.

3. Development of the optimal planning algorithm

3.1. Overview

According to some research findings from the manufacturing field, when the global behavior of a complex system is the result of interaction among many actors, it resembles the behaviour of food-foraging ants, which is called stigmergy. Even from the computational point of view, stigmergy is a very efficient approach because it is capable of incorporating nonlocal information while employing only local reality-mirroring components [12]. To sum up, the following steps are performed in a stigmergic approach:

- In absence of any signs in the environment, ants perform a randomized search for food;
- When an ant discovers a food source, it drops a smelling substance, called pheromone, on its way back to the nest while carrying some of the food. The pheromone trail evaporates if no other ant deposits fresh pheromone;
- When an ant senses a pheromone trail, it will be urged by its instinct to follow this trail to the food source and will deposit pheromone itself on its way back to the nest.

This pattern is an emergent behavior of the ant colony, that is ordered and is robust against the uncertainty and the complexity of the environment. Although information about the presence of food is made available locally, it affects the global behavior of the colony and the state of the environment.

The algorithm presented in this paper is an extension of the multiple ant colony system for vehicle routing problems with time windows (MACS-VRPTW), which is reported in sub-section 3.2. The enhancement proposed by the authors is detailed in sub-section 3.3 and concerns some steps for overall cost optimization. For the sake of clarity, Fig. 1-a depicts the whole logic: the grey boxes framed with a solid line represent the typical steps found in a MACS-VRPTW algorithm, whereas the white dashed-line boxes depict those parts of the algorithm that were added to perform what is described in sub-section 3.3.

3.2. Multi-objective optimization through MACS-VRPTW

The basic algorithm implemented to perform optimization was the vehicle routing problem. Indeed, driving crews along the most cost-effective path recalls problems about routing optimization. More specifically, we refer to the multiple ant colony system for vehicle routing problems with time windows (MACS-VRPTW), which performs ant colony optimization [13].

Basically, MACS-VRPTW is organized with a hierarchy of artificial ant colonies designed to successively optimize a multiple objective function: the first colony minimizes the number of vehicles while the second colony minimizes the travelled distance. A VRP is composed of n customers served from a unique depot c_0. Each customer $c_i, i = 1, \dots, n$ asks for a quantity q_i of goods and a vehicle capacity Q is available for delivery. Each delivery cannot be split and the vehicle has to periodically return to the depot for reloading. On the overall, the problem is represented as a graph made of a node set $C = \{c_0, c_1, \dots, c_n\}$ and arcs $L_{ij} = (c_i, c_j): i \neq j$ to which a matrix of travel time values t_{ij} is associated.

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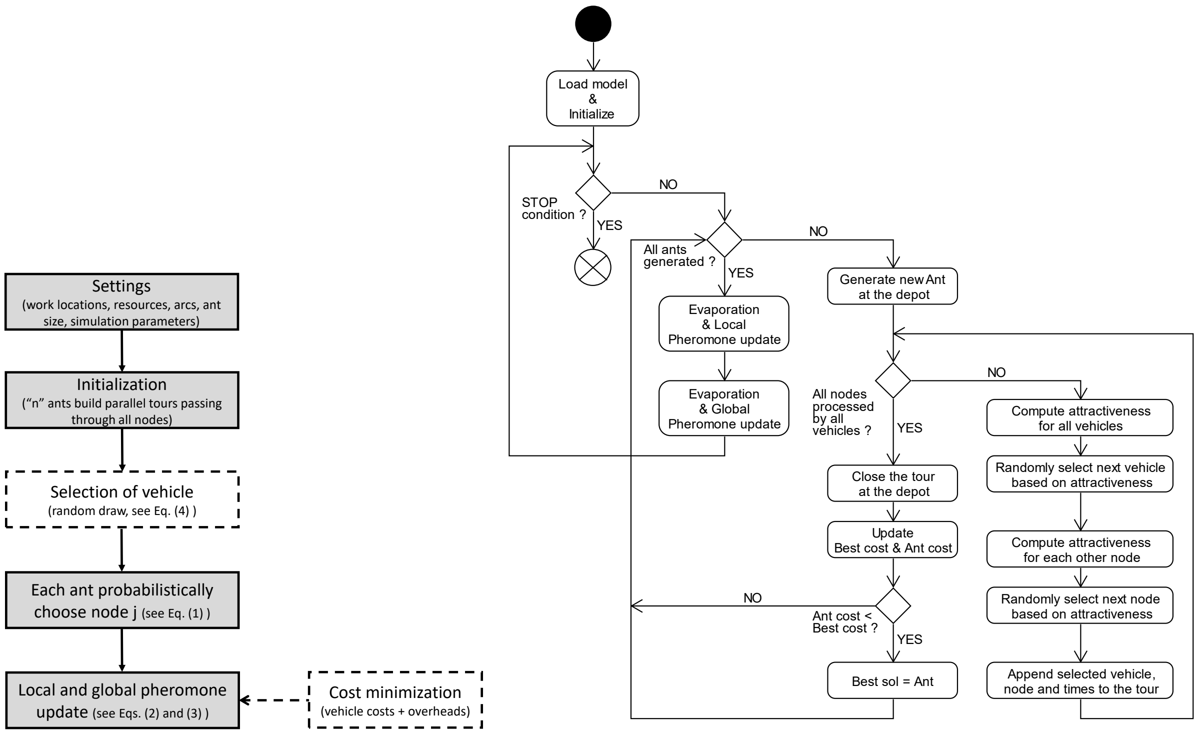

(a) (b)

Fig. 1. Overview of the enhanced MACS-VRPTW algorithm (a) and details of the MACS-VRPTW implemented in this paper (b).

The goal is to find a set of tours of minimum total travel time, where each tour starts and ends at the depot c_0. Extensions to the basic problem include: service time for each customer; duration limit of each tour.

In this paper the VRP with time windows, i.e. VRPTW, was applied. This problem includes for the depot and each customer c_i a time window $[b_i; e_i]$, during which each customer must be served (i. e. it must be served between starting time b_i and end time e_i). The VRPTW solution approach proposed in [13] assumes that the tours are performed by a fleet of identical vehicles and that the optimization is based on the Ant Colony System (ACS) that is briefly described in the following. ACS is applied for minimizing both the number of vehicles and travel time (i.e. to achieve a multi-objective optimization). To this purpose, two measures (i.e. heuristics) are associated to each arc: closeness (η_{ij}) and pheromone trail (τ_{ij}). The first one is the inverse of the distance, the second one is dynamically changed by ants at runtime. Pheromone trails are used in conjunction with the objective function to construct new solutions: a higher attractiveness is given to the arcs with a stronger pheromone trail. Pheromone levels give a measure of how desirable (attractive) it is to add a given arc in a partial solution. At runtime, n_a ants build their own tours in parallel. Each ant is assigned to the depot c_0 and must build a feasible solution, by iteratively adding new nodes until all nodes have been visited just once. When ant k (for $k = 1, \dots, n_a$) is located at node i, it chooses the next node j probabilistically in the set of feasible nodes N_k^i (i.e. the nodes that have not been visited yet and that comply with the given time window $b_i \leq t_i \leq e_i$).

The attractiveness of a node is defined by Eq. 1:

$$p_{ij} = \begin{cases} \frac{\tau_{ij} \cdot [\eta_{ij}]^{\beta}}{\sum_{c_l \in N_k^l} \tau_{il} \cdot [\eta_{il}]^{\beta}} & if\ c_j \in N_k^j \\ 0 & otherwise \end{cases} \quad (1)$$

Parameter β weighs the relative importance of the heuristic evaluation based on the distance, with respect to the pheromone trail.

The probabilistic rule, at each iteration, randomly decide between two alternative selection criteria: exploitation and exploration. This is done based on a parameter $q_0 \in [0; 1]$ that determines the relative importance of exploitation versus exploration: the higher q_0 is the more likely the exploitation criterion is with respect to the exploration criterion. Ant k with probability q_0 sorts out the next node as that one with the highest $\tau_{ij}[\eta_{ij}]^{\beta}$, while with probability $(1 - q_0)$ it selects the node as an observation of the discrete random variable with probability distribution $p_{ij}, \forall j = 1, \dots, n$ (see Eq. 1).

In the MACS-VRPTW, it is optional to include that, once each ant has built a complete solution, it is tentatively improved using a local search procedure.

The best solution is used to modify the pheromone trail matrix (τ_{ij}) as follows:

$$\tau_{ij} = (1-\rho)\cdot\tau_{ij} + \frac{\rho}{J_{\Psi}^{gb}},\ \ \forall(i,j): c_i, c_j \in \Psi^{gb} \tag{2}$$

Where $0 < \rho < 1$ and J_{Ψ}^{gb} is the length of J^{gb}, i.e. the shortest path generated by ants since the beginning of computation. Future ants will use this information to generate new solutions around the best solution.

Locally, when an ant moves from node i to node j, the amount of pheromone trail on arc L_{ij} is decreased by the amount:

$$\tau_{ij} = (1-\rho)\cdot\tau_{ij} + \rho\cdot\tau_0 \tag{3}$$

where τ_0 is the initial value of trails.

Then, the process is iterated generating again m ants until a termination condition is met. This algorithm was used in MACS-VRPTW with two objectives: minimization of the number of tours and minimization of the total travel time. To this purpose, two independent colonies are used, one per each objective, but both share the variable Ψ^{gb}.

3.3. Extension towards multiple activities

In the final version of the MACS-VRPTW we implemented in this paper (Fig. 1-b), some changes with respect to the reference version detailed in sub-section 3.2 were made. First, only the ACS-Time colony was necessary. There was no need to use another ant colony (although it can be implemented in the MACS-VRPTW), because the objectives of reducing the number of vehicles and minimizing the total travel time can be done by means of cost optimization. Secondly, the local search option of MACS-VRPTW was not implemented but it could be used for fine tuning the solution. Finally, no capacity limit was set (i.e. the Q value was not inputted and infinite capacity is assumed); however, this option was kept open and it is expected to be implemented in future versions for handling activities that require to return periodically to the stocking area.

Rather, additional functionalities were added in the final algorithm, that are necessary for the construction field, where multiple different activities are involved in the planning task. As shown in Fig. 1-b, each ant consists of all activities (vehicles) performed on all customers (nodes) by following the correct operation sequence. The time window can be differentiated for each vehicle according to the nodes and operation that must be served and the specific productivity and costs can be set for each vehicle. The computation of costs was generalized: direct costs include those ones that are generated by travelling between nodes, waiting for work (e.g. because the previous task was not accomplished in the next node) and operation (e.g. according to productivity). Also, indirect costs were added, which depend on the total elapsed time. Constraints that take into account for prerequisite activities have been added in order to enforce the correct operation sequence, hence the relationships between vehicles match the ones between activities. Moreover, the best solution is re-evaluated, compared and updated at each iteration to allow for dynamic re-planning when unexpected events occur.

The generalization to multiple activities required a double selection process for making each movement of an ant: not only the next node have to be selected but also the next vehicle must be chosen for operating in that node. When ant k (for $k = 1, \dots, n_a$) is located at node i, it chooses the next vehicle v probabilistically in the set of feasible vehicles V_k^i (i.e. the vehicles that have not visited all nodes yet) based on the number of feasible nodes n_k^{iv} for that vehicle:

$$p_v^i = \begin{cases} \frac{n_k^{iv}}{\sum_{u\in V_k^i} n_k^{iu}}\cdot\gamma & if\ v \in V_k^i\ and\ v\ was\ operating\ in\ node\ n_i \\ \frac{n_k^{iv}}{\sum_{u\in V_k^i} n_k^{iu}} & if\ v \in V_k^i\ and\ v\ was\ not\ operating\ in\ node\ n_i \\ 0 & otherwise \end{cases} \tag{4}$$

where $\gamma > 1$ is a factor used to increase attractiveness of vehicles that was already active and, therefore, to foster solutions with continuous vehicle operations. Similarly to what is done in the classic MACS-VRPTW, the next vehicle is then selected by an observation of the discrete random variable with probability distribution $p_v^i, \forall v = 1, \dots, n_v$ (see Eq. 4).

4. Simulation and testing

4.1. General framework and scenarios

The general framework we suggest in this paper is meant to be able to exploit information stored in BIM (e.g. through BIMserver) to assist in generating schedules. Indeed, automatically retrieving information from a BIM model could help achieve significant time reductions in scheduling as compared with traditional manual methods. In general, the data that can be retrieved from a BIM model are those ones regarding the material of construction components, their locations on site and quantities. On the contrary, the remaining information must be defined through inputs form the user, who is in charge of defining the maximum number and types of available vehicles and crews to perform on-site activities, the location of depots where equipment is parked when not in use, constraints about sequencing for activities. Once the algorithm is fed with these data, it can perform optimization and work out the optimal schedule, as shown in Fig. 2.

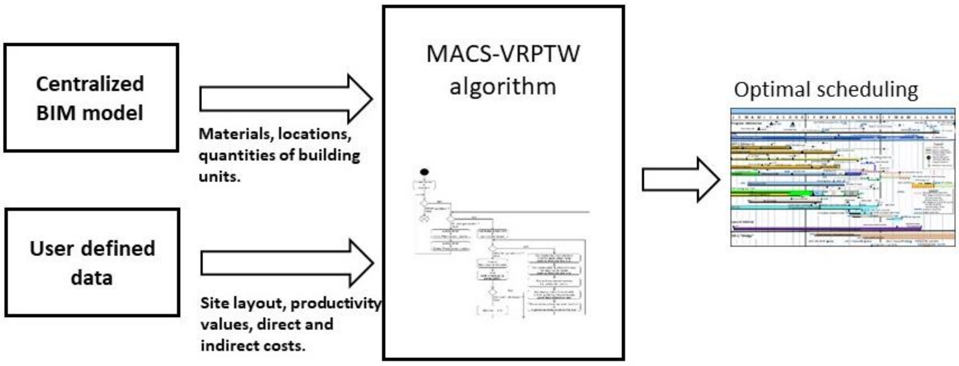

Fig. 2. Framework of the planning system tested in this paper and based on the extended MACS-VRPTW algorithm

The case study developed in this paper concerns bored piles execution, which includes a series of tasks well described in the work by Zayed and Halpin [14]. The main tasks to be performed are, as a first step, adjusting the machine on the pile axis and drilling the pile; as a second step, erecting the rebar cage using a crane; as a final step, erecting the concrete pouring tool and pouring concrete until the pile is finished. After this process is accomplished for one pile, the machines need to be relocated and the process is repeated again for the next one.

Hence, the outcome of our planning process was a schedule made of three activities (i.e. drilling, rebar, pouring), which are accommodated so as to provide the sequence of piles that must be worked by each machine and its crew (i.e. drilling machine, crane and pouring tool). Of course, at every pile the possibility for a machine to perform its task was constrained by the sequence of technical steps typical of bored piles, i.e. drilling-rebar cage-pouring. As a result, if we focus on a particular machine, the algorithm will determine the ordered list of piles where it must perform its task. To be noticed that the ordered list that is optimal for one machine can be different from the optimal ordered lists for the machines that follow the first one. Instead, the depot location was determined by the user. No restrictions in terms of time windows was set in the first application shown in this paper, which means that the algorithm was left free to find out the best solution in terms of overall costs and makespan.

4.2. Implementation

The specific layout of piles chosen to test the approach shown in this paper is the one depicted on Fig. 3, that is the plan view of the BIM model containing the project to be executed. At this point, the BIM model was made of just 32 piles on three curved rows, numbered as shown in the figure. Although not fully automated, the quantity take-offs were extracted directly from the corresponding BIM model. These datasets included piles diameter, depth and volume.

Productivity of drilling activities were estimated according to international literature [15], because it provides values averaged over the most common types of soil and machines that can be adopted. The other productivity values (i.e. rebar cage positioning and concrete pouring), direct and indirect costs were derived from databases and software tools for the estimation of unit costs of activities referred to the Italian context [16]. The productivity and costs values inserted in the algorithm are shown in Table 1, where it can be noticed that overheads are high as 50 €/h and were attributed to the whole construction site. Additional indirect costs were accounted to the equipment. Denoting $\bar{d}$ as the mean distance between nodes, the other parameters used to run the algorithm are: $n_a = n$, $\tau_0 = 1/(n \cdot \bar{d})$, $q_0 = 0$, $\beta = 2.5$, $\rho = 0.5$, $\gamma = 15$.

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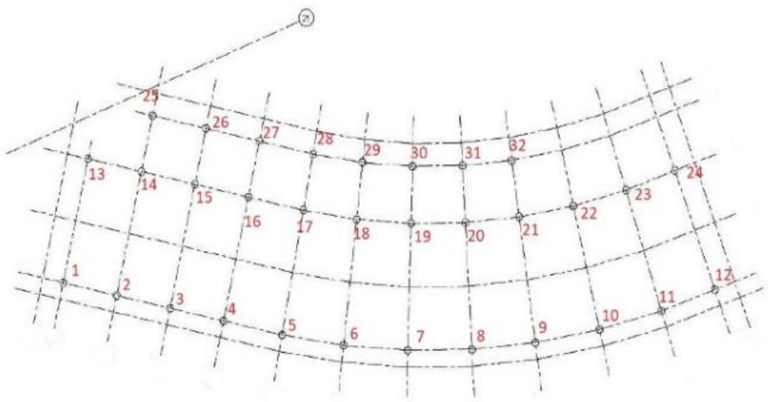

Fig. 3. Layout of bored piles whose optimal planning was automated by means of the extended MACS-VRPTW.

Table 1. Productivity and costs values inserted as inputs in the MACS-VRPTW.

Type of value	**Drilling machine**	**Rebar cage**	**Concrete pouring**
Productivity	10.00 m/h	0.16 t/h	2.86 m/h
Direct costs	83.32 €/h	74.96 €/h	162.00 €/h
Indirect costs	23.74 €/h	10.86 €/h	10.32 €/h
Travelling speed	1.50 km/h	1.50 km/h	1.50 km/h
Overheads (job-site)		50.00 €/h	

The MACS-VRPTW applied to this case study gave back the optimal schedule shown in Fig. 4-a, where the y-axis reports the list of activities: no. 1 is drilling, no. 2 is rebar cage erection and no. 3 is concrete pouring; the x-axis reports the elapsed time. Fig. 4-b depicts the number of iterations vs the value of the cost function related to the work execution.

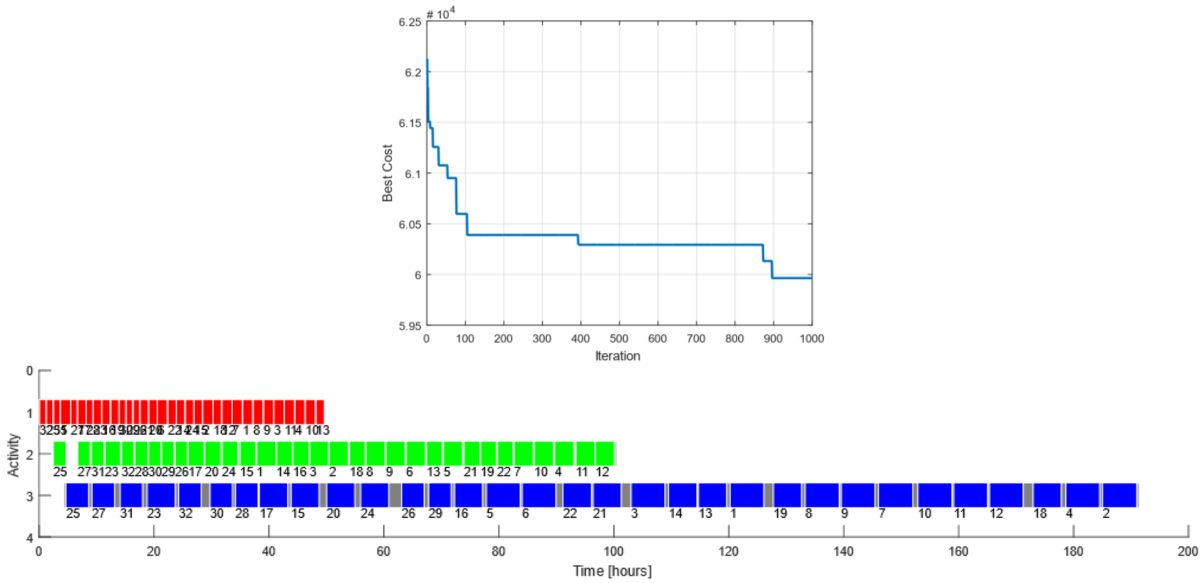

Fig. 4. Trend of the best cost (top) and final optimal plan for the execution of bored piles (bottom).

4.3. Discussion

As expected, the ordered lists of piles suggested for the execution of the three activities by the respective involved machines is not invariable. In fact, the sequence of piles worked within the first activity is different from the sequence of tasks worked within the second activity which is, in turn, different from the third one. In addition, the work performed by the three machines is interrupted by waiting times, that are necessary when a machine cannot perform its task until the previous one is not accomplished at the pile it has ordered as the next one on the list. Indeed, waiting times increase indirect costs, but sometimes they can be accepted if the total travelled distance and related costs decrease. For example, the average waiting time for the second machine is equal to 0.06 h. Hence, this algorithm performs a trade-off between direct and indirect costs. The overall time to perform all the activities (i.e. makespan) is equal to 191.4 h. The total cost of the work performed is equal to 59,964 €. Finally, it must be noticed that this solution is the one that the algorithm worked out after 1000 iterations, as depicted on Fig. 4-b. Due to the nature of the algorithm, it could be capable of improving the suggested solution while increasing the number of iterations, until it stabilizes to the best one. However, when the optimization process must be quick, like in dynamic planning, this algorithm is always able to provide a sub-optimal solution within a pre-determined time limit, e.g. if we had stopped after 800 iterations, the solution provided at that point would have been slightly worse than the one suggested after 1000 iterations.

5. Conclusions

An overall framework for automated planning of construction works was presented in this paper. It consists of several units: one unit is expected to retrieve information about building component materials, locations and geometry directly from the BIM model, without human intervention; one unit will manage information about the construction sites (e.g. locations of depots); another unit will implement the MACS-VRPTW algorithm to automatically generate the optimal schedule; the last unit will visualize the resulting schedule. The MACS-VRPTW algorithm developed in this paper performs optimization through the application of the stigmergic technique, which is based on ant colony search for the optimal solution. It belongs to the wider category of multi agent-based simulation, which looks very suitable for construction, where the overall behavior can be interpreted as the result of the interaction between several agents (i.e. crews), each one pursuing its own objective but obliged to interact with the remaining resources and with the context.

In the algorithm presented in this paper, not only the overall makespan, but even the total costs of the construction site under analysis were optimized. The results show that after 1000 iterations the algorithm was able to optimize the overall cost function and to work out a solution that could limit the average waiting time of each crew. Also, it visualized the optimal schedule for the case study under analysis, according to the provided inputs. Among the main benefits, we cite the very efficient computational capabilities and the dynamicity of the algorithm, that can be run even in real-time during work execution, if revised planning is requested after deviations occurring from what expected.

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Dynamic 4D Space Planning Using Chronographical Modeling

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Abstract

Over the past decade, many studies and software have combined the 3D digital models of the BIM (building information modeling) with the traditional Gantt / Precedence scheduling networks to simulate a 4D modeling for construction projects. These simulations demonstrate the sequences of the work implementation with the aim of correcting scheduling errors, resolving execution conflicts and optimizing the work plan. Originally, BIM models were intended for design perspectives. However, when applied to the construction and operation phases, they require significant efforts to revise the schedule and the BIM model, particularly to characterize the spatial nature of the projects. Modeled with a method that demonstrates a bar Chart, better known as Gantt diagram, that uses the Precedence logic, construction projects schedules represent graphically the activities, their constraints, their floats and the critical path. Despite the almost exclusive popularity of this method, its representation of the construction operations remains deficient. This logic ignores the spatial site occupation aspect related to operations and teams' rotation, traffics and intermediate stocks. Space planning schedules methods represent a good solution to these gaps. The Chronographic modeling, a space planning method has the ability to alternate between visual representations approaches using a set of graphical parameters. Each approach can help to model adapted schedules for different project types and specialties, shows valuable information in a clear and comprehensible manner and facilitate solving construction site problems visually. The purpose of this paper is to present a communication strategy between a 3D-BIM model, the Chronographic Modeling, and a 4D simulation tool. The development process consists of four steps. The first is to set the numerical parameters to adapt the model to space construction management perspectives. The second studies the different possibilities of communication between the three models. The third presents the scheduling through the Chronographic Modeling and the last one concerns the 4D simulation.

Keywords: BIM; 4D; Chronographical modelling; Scheduling; Space-planning.

1. Space management on construction site

Space allocation and management during the construction process of building projects have a direct impact on the time, the cost and the security of a project [1]. Despite this fact, project managers often underestimate this discipline [2]. One has to consider that space management on building sites remains a difficult task. On one hand, space occupation can vary according to the type of use, namely, the site as occupied by process, including storage, circulation and access to the site, or the site as occupied by products [3]. On the other hand, these spaces will evolve according to the different construction phases [4]. Moreover, each construction project is unique so it is difficult to establish a universal method for construction space management.

Several studies have investigated construction space management. Some of them suggest characterizing spaces by occupation state (free, occupied) [5], some depending on their purpose (storage, work, traffic) [3] or according to the different contractors'/subcontractors' needs. Some models describe the area patterns as dependent on the tasks to

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accomplish [3] or according to their physical evolution [6]. The common objective of these studies is to identify space congestion in order to avoid delays. In fact, the negative impact of space congestion on site productivity is a well-known problem in construction. Since 1989, [7] has estimated an efficiency loss of about 65% due to space congestion.

According to leading research, one can identify two main categories of spatiotemporal conflict detection: i) the algorithmic approaches [5, 6], and ii) the visual detection method with 2D representation [3, 8, 9, 10].

2. BIM and 4D simulation

Since the arrival of Building Information Modeling and 4D simulation, it has become possible to confront the project schedule with three-dimensional representations in order to detect planning errors and conflictual situations. To do this, it is necessary to create links between construction activities and the 3D geometric model. These types of simulations could help schedulers better comprehend site management and project constraints [11]. In addition, 4D simulation allows for the study of different scenarios [12]. Even though the first commercial tools appeared in the 1980s [13], the arrival of BIM has made this discipline considerably easier, especially with the capability to reuse BIM to simplify the creation of links between activities and the 3D objects [14]. To perform 4D simulations, specialized commercial software has been developed. Navisworks software links the schedule activities to the geometrical component of the 3D Revit model to help to review the scheduling, analyze conflicts, communicate execution process, coordinate disciplines, resolve clashes and plan the project before construction begins. The 4D simulation process then requires many round trips between the two programs to process the changes [15]. Synchro software uses the Critical Path Method logic directly, then the scheduling and the 4D simulation are in one unique tool. Vico's software uses a linear diagram to model the spatial dimension (Location Breakdown Structure) with the schedule.

These 4D simulations model either a bar chart diagram, with precedence constraints that hardly represent time-space constraints, or a linear diagram scheduling method that does not suit model-building projects. Indeed, it is hard to show the spatial aspects and circulation on the construction site [4]. Tools that apply the Gantt chart rely on communication with planning software such as MS Project or Primavera to complete the schedule.

3. The Chronographical modeling

The Chronographical method [9, 10, 16] is a more complete graphical model for construction schedules. The Chronographical approach describes how schedule information can be communicated using tabular and graphical interfaces to manage specialties, locations, means, processes and constraints on different strata. It can be shown either separately or together using layering, sheeting, juxtaposition, alterations or permutations while allowing for groupings, hierarchies and classification of project information. This graphical modeling has the ability to alternate from one visual approach to another by manipulation of graphics via a set of defined graphical parameters. Each individual approach can help to schedule a certain project type or specialty, show valuable information in a clear and comprehensible manner and facilitate the management of construction site problems visually.

The conceptual framework defines the physical entities (work, resources and locations), their properties and the logical constraints, execution process and organizational models that allow for various groupings, hierarchies, scales and attributes. These modeling strategies allow planners to alternate between different planning modeling approaches. The Chronographic method also defines the workspace management process according to the different phases of project execution. For this purpose, the method identifies five (5) distinctive phases: space creation (new floors), systems (ventilation ducts), division of spaces (partition walls), finishing trades (paint) and space closure [4].

4. Research objective

This study proposes a communication strategy between 3D BIM modeling software and the VBA Excel Chronographical scheduling application with the objective to respond to the deficiencies of existing software and scheduling methods.

5. Experimental analysis and case study

The communication strategy developed in this research aims to link the building components of the digital models to the different physical entities of the Chronographical modeling. Hence, it will be possible to define a more comprehensive schedule by combining the products, process, work, materials, tools, equipment and space. The

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developed process considered the communication constraints between the BIM model, the Chronographical scheduling and the 4D model in each stage. The case study, a fictive four-story building construction project (figure 3), has been used to validate the strategy and conduct a critical review of its use.

Navisworks allows for creating automatic rules between the 3D BIM model and the corresponding schedule activities and thereby facilitates the creation of a 4D model. However, to adequately meet the requirements of the VBA Chronographic Planning application, it implies the addition of several customized parameters in order to obtain the desired breakdown structure. Indeed, these parameters can be exploited to obtain accurate amount of work by floor, phase, area and sector to facilitate the representation of the space-planning model. Dynamo (a Revit add-in) has been used to allow communication between Revit and the Chronographical application. The developed scheduling process (illustrated in figure 1) is realized with 4 different tools and is divided into 5 steps:

- Preparation of the BIM model, using Revit, to represent the construction perspective by adding personalized information on the building components.

- Data extraction, using Dynamo, from the numerical model to aliment the Chronographical application.

- Scheduling of the construction process with the Chronographical method. This step, more detailed in the next section, results in the creation of a schedule showing the construction process and coordination between executors, works and the construction areas.

- Return of the added information, using Dynamo, from scheduling phases to the BIM Revit model.

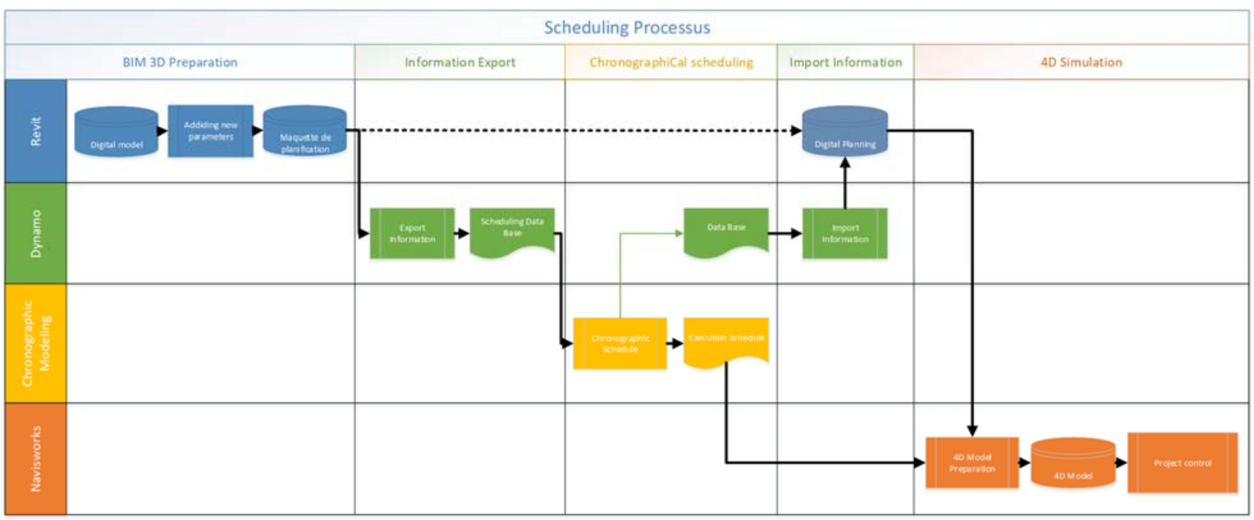


Fig. 1. 4D simulation schedule process

The 4D model is created, using Navisworks, by automatically linking the 3D BIM model and the realized developed schedule. This model shows the construction sequences of the different construction areas. This 4D simulation helps to check for space use conflicts and to calculate the site's utilization rate in order to optimize the project schedule. This tool is also a strong communication tool to explain construction sequences.

6. Preparation of the 4D simulation using the Chronographic modeling

The process aims to create a project schedule using the Chronographic modeling by exploiting the data extracted from the BIM digital model. The planning of construction projects, through the use of different presentation approaches, has already been tested in various research projects conducted in the MGPlan laboratory. The extracted data from the BIM digital model, with the Dynamo script, are shown on independent worksheets corresponding to the Revit object categories. This application, therefore, offers the possibility of modeling the project scheduling through different complementary views.

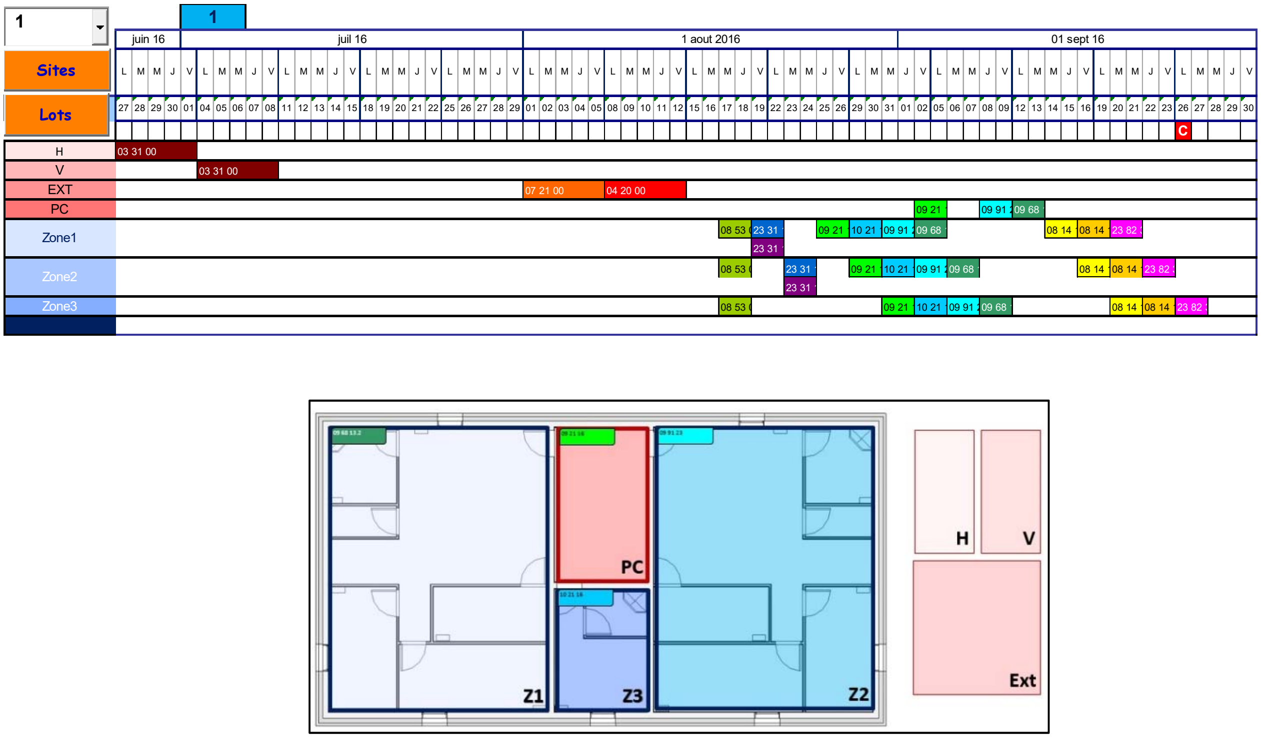


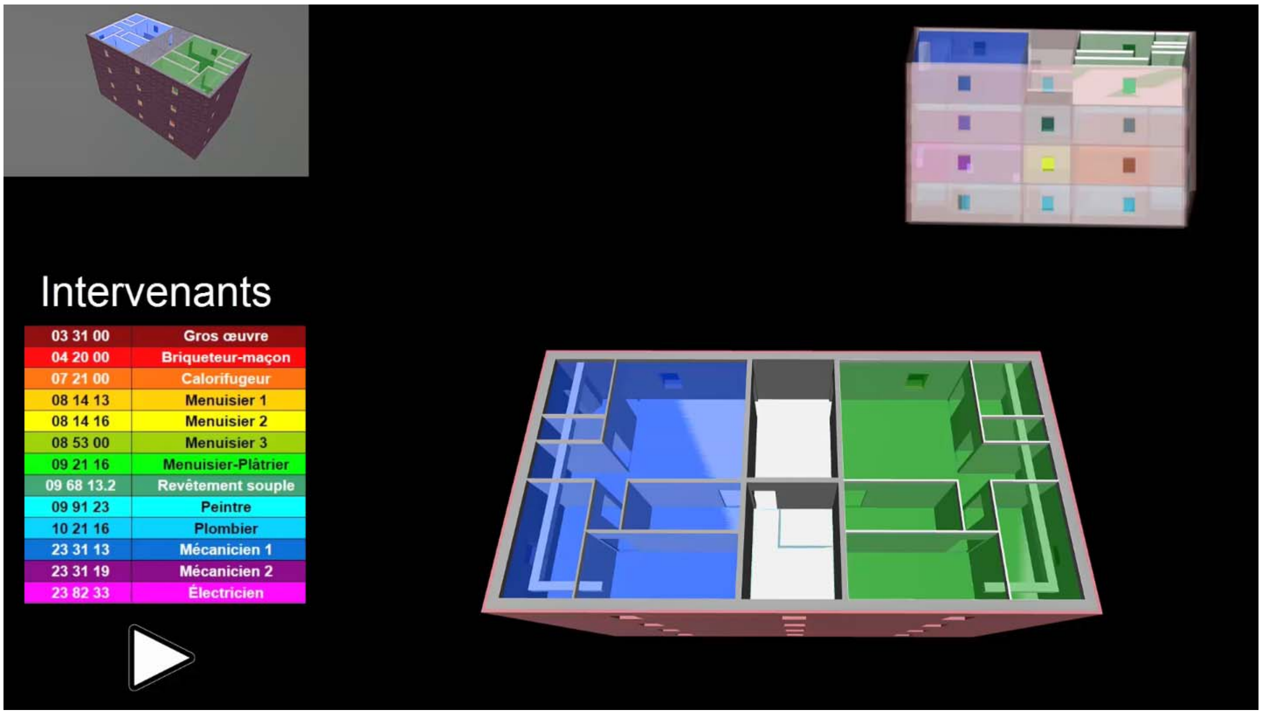
Fig. 2. (a) Grouping by site; (b) Schedule by floor

The version used in this project includes five (5) different approaches:

- A bar chart presentation that demonstrates the process of accomplishing each activity.
- A grouping by specialty for a particular floor. A modeling that vertically represents the different work zones and horizontally the time. The zones are represented by filling the activity bars with a predefined color code.
- A grouping by location for a particular floor (see figure 2.a). A modeling that vertically represents the different areas and horizontally the time. Specialties are represented by filling the activity bars with a predefined color code.
- A plan of the selected floor (see figure 2.b) on which the different areas of the floor are represented and colored according to the predefined color code. Activities are graphically represented within the different zones for a given date. This view allows for apprehending the sequence of work within a floor and calculating the site occupancy rate.
- A grouping by specialty that shows the entire building's floors. This view demonstrates the Takt scheduling [17] of the different specialties on all floors. Customizing this view allows for filtering specialties and floors.

The BIM 3D model will then be updated by returning information from the planning process exported in CSV format via a Dynamo script. The 4D model is built on Navisworks using the Timeliner tool's auto-attach feature. This model makes it possible to distinguish the different spaces in which the works intervene. The functionality of Navisworks has been exploited to demonstrate the evolution of construction in the different workspaces of the model using the predefined color ranges. This feature relies on creating elementary volumes representing spaces. From this feature results the possibility to visualize during the 4D simulation what specialty occupies which workspace over time as illustrated in figure 3.

Fig. 3. 4D Dynamic space planning



7. Conclusion

In conclusion, the use of Chronographic modeling to simulate the 4D process facilitates graphical representation of the dynamic evolution of workspaces occupied by the specialties. The research, therefore, combined the Work Breakdown Structure using the master format codes with the Location Breakdown Structure using the Chronographic space-modeling concept. On the same principle, other breakdown structures could be also used. The strategy could also be adapted to address other aspects of project planning in the implementation phase, such as the representation of circulation and traffic or the evolution of intermediate storage. The addition of colors could also provide information on the occupation type of the space (occupied by a process or a product, or used as storage space). Thus, the user could then select the appropriate views to help him or her properly manage and coordinate the project.

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Employing Critical Chain and Lean Concepts to Develop the Planning and Control Framework for Linear Construction Projects

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Abstract

A framework to plan and control construction projects by incorporating the concepts of critical chain, linear schedule, and lean construction is presented. Construction project managers need to seek the effective interaction between the variables of time and money to ensure the development and compliance of the project within the planned schedule and the budget limit. Such an interaction could further be complicated by the development of project activities involving multiple stakeholders such as specialized subcontractors in different areas of construction. Consequently, this multi-participation consists in determining the start and end of all activities carried out by different parties, as well as variations in productivity each subcontractor possesses, which greatly increases the risk of project delay and over budget. Although various methodologies have been employed to prevent such problems, lacking of control mechanism and risk management lead to ineffective practice in the real project.

This framework initially integrates CCPM (Critical Chain Project Management) and LSM (Linear Scheduling Method) to create a project buffer able to control the project in terms of time. The project buffer is obtained through the reduction of the duration of some activities belonging to the critical chain through the bonus-penalty system. In Addition, a cost buffer is included within the framework to encourage subcontractors to improve their productivity and to ensure continuity of the work, respectively. Furthermore, this study incorporates concepts from Lean Construction and EVM (Earned Value Method) for the purposes of (1) managing construction projects with a higher planning reliability and (2) monitoring and controlling the consumption of project buffer and cost buffer according to established consumption criteria.

Keywords: ;Critical Chain ; Lean Construction ;Linear Scheduling

1. Introduction

Construction project managers need to seek the effective interaction between the variables of time and money to ensure the development and compliance of the project within the planned schedule and the budget limit. Such an interaction could further be complicated by the development of project activities involving multiple stakeholders such as specialized subcontractors in different areas of construction. Consequently, this multi-participation consists in determining the start and end of all activities carried out by different parties, as well as variations in productivity each subcontractor possesses, which greatly increases the risk of project delay and over budget.

Different methodologies have emerged for effectively planning and controlling a project. The Critical Chain Project Management (CCPM) [1] focuses on eliminating the floats from activities and reallocating them into strategic positions on the critical chain. These time positions are known as “buffers”. Figure 1 shows a comparison between a CPM (Critical Path Method) schedule and a CCPM schedule, where along with a reduction of the project duration includes a project buffer at the end of the project that extends to finish at the same time as the original schedule. Then, a buffer

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management process is implemented to control the buffer consumption throughout the life cycle of the project. This project buffer has a primary objective to serve as a control mechanism of the project.

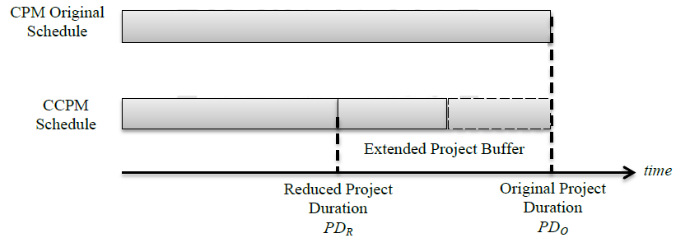


Figure 1. Project Schedule with Extended Project Buffer

Linear Scheduling Method (LSM) is developed to prevent delays or bottlenecks for construction projects on which similar construction activities are execute. LSM allows better representation of scheduling information in terms of space constraints and productivity rates, showing several advantages such as keeping work continuity and maintaining a constant and skilled workforce, which helps to maximize the use of learning curve effect of the crew [2].

Besides the scheduling approaches, some construction management strategies have been developed to manage a project during all the stages of the execution phase. The Earned Value Management (EVM) is a methodology used to measure and communicate the real progress of a project and to integrate the scope, time and cost management. It takes the work accomplished, the time taken and the costs incurred to complete the tasks into account [3]. Moreover, Lean Construction is a methodology designed to produce predictable work flow and rapid learning in scheduling, design, construction and commissioning of projects. The reviewed literature shows that some studies have addressed the integration of criticality concepts of CCPM on LSM in order to define a final schedule in the planning phase. Furthermore, there is a need to develop a cost and time management system which controls that a linear project is developed within budget and schedule previously established during all the stages of the execution phase.

2. The Proposed Framework for planning and controlling a linear construction project

Figure 2 shows the framework proposed in this study. The framework seeks to define the steps to follow for a general contractor to manage a construction project since the project is awarded until its total completion based on the lean construction philosophy.

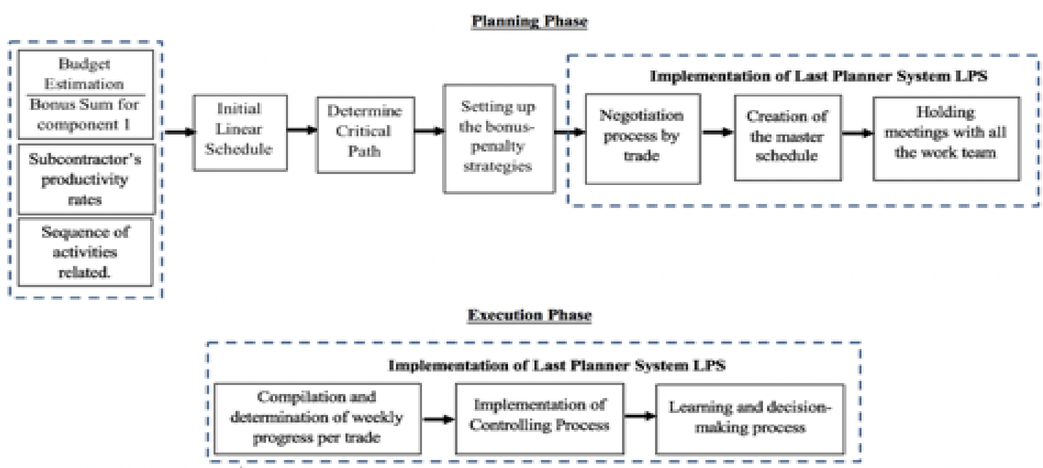


Figure 2. Proposed framework

In terms of time, the linear schedule needs to be created and modified by the duration reduction of some activities in order to create a project buffer allocated at the end of the schedule. Moreover, the feeding buffer for non-controlling segments of the project needs to be determined to avoid new activities become part of the critical path while the project is underway. In terms of cost, a bonus-penalty system and a cost buffer are set along with the traditional cost components in order to develop a cost management system for the execution phase. The time-cost tradeoff strategy together with the Earned Value Management (EVM) are in charge of monitoring and controlling the cost buffer, the bonus earned and the real time reduced by the crashed activities in order to determine the status of the project on a weekly basis in terms of time and cost. Each stage and process are explained in the following sections.

2.1. Planning Phase

2.1.1. Initial Linear Schedule and Critical Path

This study incorporates the concept of the control points developed by Harris and Ioannou in 1998 [4] for finding the critical path. The control points determine the amount of project units that need to be completed in a preceding activity in order to continue with the succeeding activity. Figure 3 shows the two types of control points that can define the critical path of a project in terms of the way the preceding and succeeding activities interact between each other. A control point for start (CPs) occurs when the production rate of the successive activity is higher than the one from the predecessor. This control point is defined between the first project units of the predecessor activity and the successor. On the other hand, a control point for finish (CPf) arises when the production rate of the successive activity is lower than the production rate of the predecessor. This causes that a control point for finish is defined when all the project units of the predecessor are completed. Once all the control points between all the activities are defined, the critical segments are determined in terms of the sequence of the activities established and the rates of their productivities. In Figure 3, the thick lines delimit the critical path comprised of the controlling segments of the project that determine the project duration.

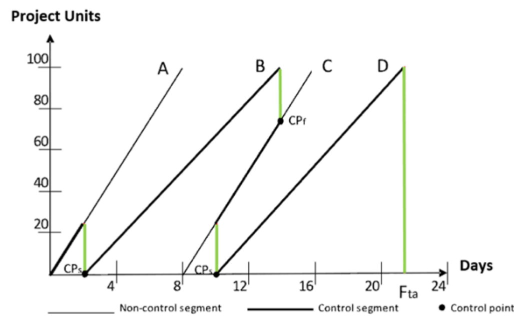


Figure 3. Critical Path Definition by determining the control points

2.1.2. Setting a bonus-penalty system

Once the critical path of the initial linear schedule is defined, it proceeds to set the tradeoff strategies for each subcontractor. These strategies are based on offering an attractive incentive (bonus) in return of reducing the duration of its activities. Reducing activity durations in LSM can be done by increasing or making equal the productivities of selected activities and therefore, increasing the slope of the line for the activity [5]. In LSM this can be accomplished by demanding a higher productivity from one crew or by increasing the number of crews [6]. In order to establish the strategies, it is first necessary to define the cost allocation involved for the project. Figure 4 describes the cost breakdown structure taken as the basis for the cost allocation in this framework, which is basically the traditional decomposition of costs, plus the addition of the bonus item.

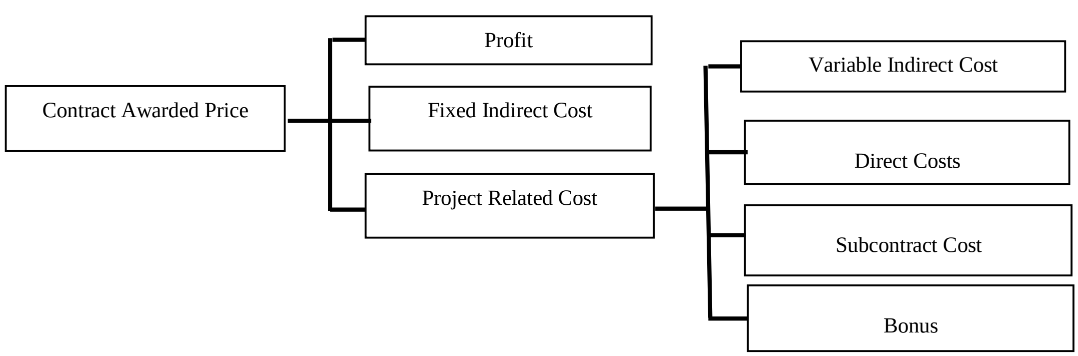


Figure 4. Cost Breakdown Structure

Bonus

The main idea of this component is to define a bonus rate, a fixed amount of money per time unit that any subcontractor can get if and only if the activities durations are reduced, regardless of their critical or non-critical status. Therefore, in order to define this bonus rate, the maximum amount that can be actually paid as bonus and the number of days required to be reduced. In Figure 5, available sum (SCAi) represents the original cost component established in the contractual price signed between the project owner and the general contractor, for a contracted activity "i", while referential bidding price (SCRi) represents the cost component established in bid between the general contractor and the subcontract for the same activity "i". The bonus component per activity is calculated as follows[7]:

$$\boldsymbol{BA_i = SCA_i - SCR_i} \quad (1)$$

BA_i: Bonus amount available for trade i. SCA_i: Available amount for trade i. SCR_i: Referential bidding price agreed between general contractor and trade.

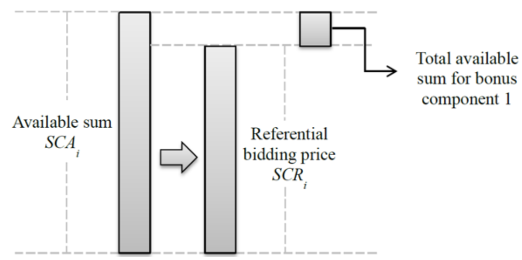


Figure 5 Bonus-Based Strategy for Accelerating Activities

After having determined the maximum amount that can be effectively paid as bonus for each subcontractor, it is time to estimate a rate per time unit. The trade off intends to define of how much the general contractor can actually ask subcontractor to reduce, which is strongly related to how much can be paid as bonus; hence this analysis must be done per each trade involved in the project. The bonus rate per time unit that the trade i can get by reducing one time unit can be determined as follows:

$$\boldsymbol{Bi = \frac{BA_i}{r_i \; x \; D_i}} \quad (2)$$

Bi: Bonus rate per time. r_i: Percentage of reduction of activity duration i. Di: Duration of activity i corresponding to trade i.

2.1.3. Negotiation process by trade

The general contractor convenes meetings with stakeholders separately once the time-cost trade off strategy per trade has been set in order to reduce the duration of its activities. The process involves two steps as described below.

Ask the feasibility of improving productivity rates: The meeting should start by letting each key subcontractor know the need to reduce the duration of its activity (improve its global productivity rate) in order to reduce the project duration, and eventually create the project buffer. This is done by introducing to the representative of the trade (the subcontractor) the existence of a bonus to earn if the goals are achieved. At the same time, the general contractor should listen and take into account any concerns the subcontractor may have.

Negotiate the activity duration reduction: Once both parties have explained their reasons, the negotiation process takes place. In this process, the general contractor must propose the time cost trade off strategy previously set up to the subcontractor. This strategy needs to be discussed together in order to agree the bonus rate per time that will govern in the development of the activity. In other words, a final productivity rate is set between the general contractor and the subcontractor in question, called *Determined Productivity (P_D)* in this framework. This is the productivity that the general contractor will demand from the subcontractor during all its participation on the project.

2.1.4. Creation of the Master Schedule

Once all the time-cost trade off strategies have been agreed between stakeholders and the total reducible time per trade is known, it proceeds to elaborate the final linear master schedule. This process initially includes the determination of the project buffer, then it is necessary to identify the critical and non-critical segments comprising the scheduling. Finally, the feeding buffers of non-critical segments are determined in relation to the type of relationships being formed with the rest of activities.

Project Buffer

In linear schedule, selecting the right activities to accelerate in a repetitive project is a very important step toward successful project acceleration [2]. Additionally, a negotiation process between each subcontractor selected to accelerate and the general contractor needs to take place in order to agree the bonus rate per time that will govern in the development of the activity. Once all the time-cost trade off strategies have been agreed between stakeholders and the total reducible time per trade is known, it proceeds to elaborate the final linear master schedule. This process initially includes the determination of the project buffer. Figure 6 shows an example for a linear schedule with 4 different activities (A, B, C and, D). The relationship between activities indicates that activity A and C have the same productivity rate. Also shows that activity B has a lower productivity than its predecessor activity A. Activity C has a higher productivity than its predecessor B and successor D. Moreover, the end of the project corresponds to the original project duration (PDo). From Figure 3, it can be seen that activity B and D have the lowest productivity rates and therefore, they have a high influence over the project duration. Figure 6 shows the same set of activities from figure 3 but with a notable increment of productivity rate B. This causes that the relationship among activities change a little and therefore, the end of the project corresponds to new crashed duration of the project (NCD). The time difference between PDo and NCD creates the size of the initial project buffer (IPB).

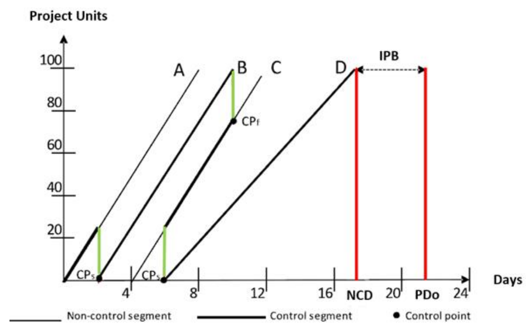


Figure 6 Linear Schedule after applying time-cost tradeoff over activity B

Cost Buffer and Cost Buffer Allocation

This study proposes the inclusion of a cost buffer in order to manage the uncertainty of the cost estimate when developing a budget in the planning stage. The cost buffer is usually used for dealing with unexpected events during the construction process in critical activities. For this research, the total cost buffer of the project was considered as the amount of variable indirect cost designated for the time units that represent the initial project buffer (IPB). Therefore, the total cost buffer available for a project (CB_T) includes the variable indirect cost rate (VIC_R) per time unit with the total duration of the initial project buffer (IPB). $CB_T = VIC_R$*IPB.

It was defined according to the assumption that the variable indirect cost (VIC) is associated to the subcontractor cost of the critical segments ($SDC_{C\text{-}Chain}$). This association is due to both cost components have a direct relationship with the project duration because the critical chain segments of the linear schedule control the project duration and the total variable indirect cost spent in a project directly depends on the project duration. Furthermore, this research includes a new approach for monitoring the interaction between the bonuses earned with the cost buffer consumed. The cost buffer is only allocated to the controlling segments of the project. The allocation process starts with the partition of the project into sections bounded by the controlling segments. For each section, the percentage of the budget that represents is estimated by including all the subcontractor direct cost for the different subcontractors (SDC) and the variable indirect cost scheduled in the master. Later, the allocation for each section takes place by multiplying the weighted values with the total cost buffer amount. Finally, it is necessary to determine the total cost buffer amount for each section in a cumulative way. Different sections in the project is defined to include all the cost assigned to the scheduled works of the different trades within the development of each of the controlling segments. For each section, the total cost is calculated to determine how much weight it has in the total cost of the project (weighted value) to finally allocate the cost buffer in a proportional way.

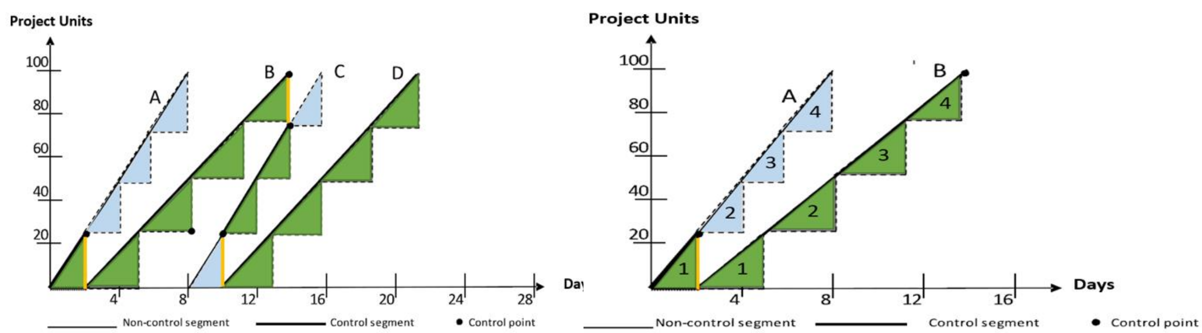
Determination of feeding buffers in the critical path

In the case of linear schedule, the relationship between one activity and another can be seen in terms of repetitive number of units or “batches”, on which the start of a batch from a succeeding activity is conditioned by the completion of a preceding batch (Shim and Yoo, 2013).[9] Figure 7(a) shows in green the controlling batches, and in light blue the non-controlling batches for a linear schedule consisting of four activities. Figure 7(b) shows the relationship between activity A and B in terms of the interaction of their controlling and non-controlling batches. From the relationship can be seen that the first batch of activity B (1B) only can start when the first batch of activity A is completed. Also, it can be observed that the productivity rate of the predecessor activity (A) is higher than the successor activity (B), which causes that the non-controlling batches of A (2A, 3A, and 4A) still have float time from their scheduled finish time until the scheduled start of the controlling batches from activity B (2B, 3B, and 4B). These float times calculated per batch become the feeding buffers of the non-controlling segments of activities that at least have a segment within the critical path. For instance, the feeding buffer of the second batch of activity A respect to the second batch of activity B is calculated using the following expression:

Feeding buffer of batch 2A respect to batch AB (FB1)

Scheduled completion time of 2A = TF-2A

Scheduled start time of 2B = T S-2A FB1 = TS-2A – TF-2A



(a) (b)

Figure 7 Relationship between Control and Non-Control Batches of two activities

It is important to mention that the feeding buffers in the non-critical chain also need to be determined according to the type of relationship that each of those activities interacts with either critical or non-critical activities. Finding buffers of the non-controlling segments seeks to monitor and to prevent this segment to become critical in the future.

2.2. Monitoring and controlling the status of the project

The second section of Figure 2 depicts the set of steps proposed in this study is to monitor and control the development of the project. In summary, the steps initially include that subcontractors already in operations are required to report their weekly performance at the end of each work week. Then, with the information retrieved the general contractor has to develop the controlling process that includes the determination of the progress of each trade, the project buffer consumption, the cost buffer consumption and the evaluation of the indices obtained. Moreover, finishing the controlling process the general contractor must convene a meeting with stakeholders in order to define the actions required to keep developing properly the works for the next week. Each part of the process is explained in more detail below.

2.2.1. Determination of progress of each trade, %Complete

Based on the information reported by each subcontractor currently working in the project, it is estimated the percentage of progress each trade has obtained. This study considers the participation of two types of subcontractors in terms of the way their performance can be measured in a more accurate way.

For the trades (TD) in charge of works in which all their progress can be well represented in a single unit of measure, the %Complete is calculated from the relation between the cumulative units of measure of the project already completed ($UC_{(TD)}$) and the total units of measure of the project ($UT_{(TD)}$).

$$\% \, Complete = \frac{U_{C(TD)}}{U_{T(TD)}} * 100 \tag{3}$$

2.2.2. Determination of Project Buffer Consumption

The applicability of the Project Buffer Consumption methodology is just focused on the critical segments that control the total project duration. In other words, through the use of the control points between subcontractors previously determined at the planning stage, it is possible to apply the methodology on a linear scheduling. The process is based on determining whether the project is running behind or ahead schedule. If the project has experienced some delays during the week, it is necessary to determine how many days the project is behind the master schedule. First of all, it is estimated the real date the units associated to the critical segment will be completed for the trade. This is obtained by subtracting from the total quantity of its critical units (**U_{TCS}**), the units of work completed so far **(**U_{CCS}), as well as by assuming the critical trade in question will work at a constant contractual productivity (determined productivity, P_D) from the date of analysis until the remaining units belonging to the critical segment are done. Finally, the estimated date of completion is compared with the scheduled date the critical segment should have been completed (T_{ED}). The project buffer consumption can be determined as follows.

$$\boldsymbol{PB_{CM} = \left[N + \frac{U_{TCS}-U_{CCS}}{P_D}\right] - T_{ED}} \tag{4}$$

Then, the percentage of project buffer consumption in relation to the initial project buffer time **(IPB**) is determined, as follows.

$$\%\ \boldsymbol{PB_{CM} = \frac{PB_{CM}}{IPB}} \tag{5}$$

2.2.3. Determination of Total Cost and Cost Buffer Consumption

Total Cost, AC

The first step is the determination of the actual cost that the project is having until the date of analysis. Its determination includes the calculation of several cost components for each of the subcontractors currently working on the project. Below is explained in detail how the process is carried out. For each trade has to be calculated the subcontractor direct cost **(AC_{SDC})** that represents the direct cost to be paid to the subcontractor by work done. Likewise, the bonus earned **(BE)** for the subcontractor is calculated if only if the percentage of progress **% complete** reaches a 100 value. Obviously, the amount of bonus earned depends on the difference between the real date of completion **($T_{RDTOTAL}$)** with the planned date of completion of the works **($T_{PDTOTAL}$)** by the trade in question. Table 2 shows an example of how a trade is monitored on a weekly basis within this framework from the beginning to the end of its participation in the project. Furthermore, the Actual Variable Indirect Cost **(AC_{VIC})** needs to be calculated on a weekly basis. It comes from the current project duration (N) and the variable indirect cost rate **(VIC_R)** defined by the general contractor prior the beginning of the execution process. Table 3 shows the table format proposed for the determination of this cost component. Then, the total Actual cost **(AC_T**) is estimated through the summation of the actual subcontractor direct cost of all the trades **($AC_{SDC\ CUM}$),** the actual variable indirect cost **(AC_{VIC}),** and the bonus earned **(BE)** for the subcontractors that already complete their works.

Cost Buffer Consumed, CB_{CM}

The second step corresponds to the determination of how much cost buffer has been consumed so far. Below is explained in detail how the process is carried out. First of all, it is necessary to calculate the earned value of the project he calculation of the consumption of the cost buffer includes the calculation of the cost variance of the project **(CV)** by comparing the budgeted cost performed with the actual cost incurred in the project without including the bonus earned. The following expression shows the way the **CV** is calculated weekly.

$$\boldsymbol{CV = EV - [AC_{TOTAL-WEEK\ n} - BE_T]} \tag{6}$$

Then, the determination of the cost buffer consumed to week of analysis comes from the assessment of the weekly cost variance value. Table 4 shows the assessment of the weekly cost variance value obtained.

If CV > 0	$CB_{CM} = 0$	There is no consumption of cost buffer.
If CV < 0	$CB_{CM} = \lvert CV \rvert$	Cost buffer is being consumed. Needs to be evaluated if the consumption is within allowable limits to determine if the cost is over budget or not.

3. Conclusions

The framework proposes a methodology for the general contractor to plan and control a linear construction project. It includes the steps necessary to manage a project from the planning stage to execution. The development of the project schedule is carried out based on the integration of the concepts of the Critical Chain Project Management on the Linea Scheduling Method in order to provide cohesion and continuity in projects developed under the linear approach. The implementation of a bonus-penalty system seeks to reduce the duration of certain project activities by increasing the productivity rates of the subcontractors in charge of them, while they are given the chance to win a bonus. The establishment of a project buffer that is allocated at the end of the project gives the general contractor a mechanism to control the critical chain in terms of the contractual date of completion.

Methodologies like the Buffer Management and the Project Buffer Index are also included in the implementation of the monitoring process of the project buffer. Their contribution falls on the establishment of the criteria that define the status of the project in terms of buffer consumption and the percentage of progress of the critical chain. The Earned Value Management has been addressed within the framework for developing the cost management process. This process involves the evaluation and control of the cost buffer consumption by measuring project progress in monetary terms. In other words, the cost management is based on constantly monitoring the "Cost-Buffer Consumed – Bonus Earned" interaction because, as long as the bonus available for each trade is totally or partially earned by the subcontractors who have done a good performance along the project, the Cost Buffer consumed will be within the allowable limits given by the budget. The importance of creating these control points is to control that non-critical batches never become critical along the project and subsequently, extend the project duration. However, during the execution phase the feeding buffers of some non-critical segments need to be updated as long as the critical segments they have relationship with, have delays and consume project buffer. Finally, it is worth noting the Lean Construction concept is the philosophy that governs the framework of this research. This concept is included in all phases of the project. During the planning phase, it is applied to empower the integration of all project stakeholders in order to develop an efficient and achievable final master schedule. On the other hand, during the execution phase, Lean Construction philosophy seeks to improve the coordination among all project participants as well as their performance by conducting weekly meetings.

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Influence of Network Structure on Schedule Performance – Extending Criticality Index to Capture Ripple Effect of Delays

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Abstract

Many construction projects suffer delays. This situation is exacerbated in larger projects with their more complex schedules, because of a 'ripple effect' – the phenomenon that relatively small delays of activities may not just locally affect direct successors in a network schedule, but spread, accumulate, and globally impact its project finish date negatively. This research therefore studies the occurrence and behavior of said ripple effect by examining dependency structures of network schedules systematically. Its contribution to the body of knowledge is threefold: First, it develops a methodology that multiplies the elements from the correlation coefficient matrix with the reachability matrix to measure said ripple effect. It plots the cumulative product matrix in three dimensions to visualize the relative potential ripple effect of individual activities. Second, it conducts a sensitivity analysis by experimenting with schedule structures that range in complexity from sequential to parallel. A constant relation is found that the sum of the product of elements in the noncumulative productive matrix and its corresponding criticality index always equals one. Cruciality is defined. Third, it substantiates its results by simulating a benchmark schedule and derives practical suggestions for delay avoidance and delay analysis that considers how the network structure determines the behavior of a schedule.

Keywords: Beta; delay analysis; ripple effect; schedule performance; simulation.

1. Introduction

'How is my project doing?' is a question that is constantly on project managers' minds. This question touches upon fundamental dimensions of project planning and control, namely the conceptual 'iron triangle' of time, cost, and scope, to which quality and safety are often added [1]. Quality of work products is routinely established [2] by many state and Federal government agencies by establishing performance (e.g. compressive strength of concrete) or prescriptive specifications (e.g. on-center distance of roof rafters), or by specifying certain manufacturers and models of installations or acceptable equivalents. It is trackable by number of defects or rework [3]. Safety is closely related and can be measured equally well via the recordable injuries and fatalities per the Occupational Safety and Health Administration regulations [*ibid.*] and is strongly financially incentivized via the *Experience Modification Rate* [4], a three-year running average of actual versus expected claims, which gives an intuitive and unitless percentage value.

But measuring performance of non-physical aspects is surprisingly challenging. The *Earned Value Management* divides said question into being 'on schedule' and 'within budget'. Accordingly it compares planned and actual time and cost values at the resource-level or activity-level within construction projects. It casts performance into absolute and relative terms as time and cost variances and time and cost performance indices, respectively [5]. But this creates some odd and counterintuitive problems [6, p. 18]: "*A major problem with the schedule performance index is that it will always be in unity when the project is completed, regardless of whether the project is ahead, on-time, or behind*

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schedule." Just because a project is finished, its performance has a value of one and the performance appears to have been perfect, even if in reality it may have been massively delayed. "*Another problem with the schedule indicator is that the SV* [schedule variance] *is measured in monetary units, which makes it difficult to understand*" [*ibid.*, p. 18].

A recent study repaired these two problems by adding an 'earned schedule' in time units [7]. It was determined in a cost-over-time coordinate system by reading a *Planned Value* on the planned progress curve for the current time, moving horizontally until intersecting the same *Earned Value* on the actual progress curve, and moving downward to read *Earned Schedule* on the time axis. If it was less than the current time, the project was behind schedule. Related studies surveyed by [5] created the conceptually identical *Earned Duration*. But fundamental problems remain: First, its forecasting ability is limited to extrapolating the current trajectory within a project [8]. Second, it ignores previous performance of a particular subcontractor, which – if evaluated in a statistical manner – could give valuable insights. Third, it precludes extrapolating beyond completed known projects to forecast the expected performance of future projects. Fourth, its approach does not offer scalability to compare performance at various levels of detail that range from activities (or even tasks) via stages and phases to entire projects, portfolios or programs of multiple projects by companies or agencies, and industry sectors. And fifth, it completely ignores the structure of the network schedule with which most construction projects are planned and controlled, which is significant for how delays may impact a project. The former items are currently being explored under related research [9]; the latter is the topic of this paper.

2. Literature Review

Performance in construction project scheduling means the ability of the productive resources to set and meet their target dates, in other words, to plan and control at an appropriate levels of detail. Extracting and ranking potentially causal or risk factors for delays from project data [10, 11], synthesizing them [12, 13, 14], or – conversely – critical success factors [15, 16] received much scientific attention. Moreover, many studies documented the phenomenon of pervasive delays across various types of projects [17, 18, 19] and in different countries [20, 21, 22]. Furthermore, a host of delay analysis methods were developed [23, 24, 25, 26], all of which had limitations and exhibited larger or smaller biases toward owner or contractor [27]. This impacts whether they are considered excusable, compensable, both, or not [28, 29]. But a major gap exists in the literature with respect to understanding how delays themselves occur and propagate within schedules: For network schedules, several potentially influential factors have remained largely ignored, notably [30, pp. 510-511] "the analysis and classification of the shape or morphology of each project network; the automatic production of easily readable graphic representations of the network to have a visual image of the network's morphology; [and] the relationship between the morphology and the uncertainty concerning the total duration of the project." To describe schedule network structure quantitatively, complexity indices were explored and defined by various scholars. Nassar and Hegab [31] developed a complexity measure based on the connectivity between activities without considering redundant links. Nassar [32] also evaluated the correlation between network complexity and project complexity. Sinha *et al.* [33] developed a metric for project complexity from the project manager's view, which considered complexity-generating factors of skill and experience of workers. Vidal *et al.* [34] (echoed by Sheard [35]) advocated that project performance depends on project complexity, which ideally should be managed not by minimizing it, but maintaining it within an optimum range. Latva-Koivisto [36] identified criteria for a good complexity measure by comparing alternative measures from graph-theory literature of mathematics.

2.1. Performance Measurement

Numerous scholars have conducted research on project performance measurement. Haponava and Al-Jibouri [37] developed a process-based key performance indices system to evaluate projects' performance when they are still in process. Nassar and AbouRizk [38] expanded performance measurement to an integrated system that considered critical objectives and transferred them into a single performance index by assessing priority weights for them. Esmaeili *et al.* [39] reviewed independent variables that led to project success on various completed projects. Sarhan and Fox [40] and Lyer and Jha [41] summarized critical factors that affect project performance in Great Britain and India, respectively. Tavares *et al.* [30] explored the relation between project delay and the morphology of its network. They defined six indicators per Table 1 to describe the morphology, generated randomized networks, calculated the indices, and determined their relationship with the total project duration. They included defining indices for activity count, relative longest path length, network width in each sequence step (termed 'progressive level'), and relative link density. But this study interpreted (non-redundant) links in network schedules to have a length akin to distance and its understanding of morphology remained limited to an overall enveloping 'shape' of serial versus parallel, i.e.

sequential versus concurrent networks. Its indices I_1-I_6 only measured global network topologies, while the total duration distribution and its mean and standard deviation were also at the global level. But at the local (activity) level they only stated confusingly that "for each activity, i, the mean μ_i is generated using an uniform generator, a_i, within $[a - \Delta, a + \Delta]$ and scaled in order that the total duration, TD, of the critical path, CP, assuming that the duration of each activity, i, will be equal to its mean, μ_i, will be made equal to 1000" [*ibid.*, p. 520]. In simpler words, its very limited approach did not consider how variations in the duration of individual activity affect total project duration, it did not experiment with behavior of different structures, and no comparison to other complexity indices was offered.

Table 1. Six morphology indicators of a project network (Adapted from Tavares *et al.* 1999)

Perspective	Index	Formula	
(A) Graphical shape	I_1	$I_1 = N$	Size equal to activity count
	I_2	$I_2 = (M - 1) / (N - 1)$	Relative length: How serial is shape
		Where length $M = \max_{i \in \Omega} a_i$ and 0 (parallel) $\leq I_2 \leq 1$ (serial)	
	I_3	I3(a) = $W(a) - 1 / (N - M)$	Only meaningful if $N > M$
		$\Sigma_{a=1} I_3(a) = 1$	
		Width: Activity count per progressive level	
(B) Count of non-redundant direct precedence links D	I_4	$I_4 = n(1) - N / (D - N)$	Relative link density with length equaling 1
		Where $0 \leq I_4 \leq 1$, because $n(1) \leq D$	
(C) Length L of non-redundant direct precedence links		$0 \leq I_5 = p \leq 1$, where $0 \leq p \leq 1$	
		$0 \leq I_6 = (V - 1) / (M - 1)$, where V is maximal length $\leq M - 1$	

2.2. Beta Index and Correlation Coefficient

To assess how variations of individual activities affect the project schedule performance, the authors are inspired by measuring financial performance from which they have developed a macro-level index (across multiple projects), whereas the correlation coefficient that will be used in this paper resides at the micro-level (within a single project).

In finance, beta is a volatility measure that describes the sensitivity of the returns of a stock relative to its market [42]. Per Equation 1, beta is the ratio of covariance between stock return and market return to the variance of market return. It is similar to (but not the same as) the formula of correlation coefficient of Equation 2, which divides the covariance of stock return and market return by the product of their standard deviations [43]. Note that beta does not have boundaries like the correlation coefficient. The latter is between -1 and 1, where -1 means that stock and market move opposite to each other, 0 means that they have no relationship, and 1 means that a stock moves with its market. But beta values could exceed this range [44, 45]. They are mathematically related by Equation 3, where beta equals the correlation coefficient multiplied by the standard deviation of the stock divided by the standard deviation of the market. Having successfully adopted the beta concept to measure scheduling performance under prior research [9], a summary is provided here: Suppose one subcontractor participates in multiple projects (market), then the volatility of its schedule performance relative to those projects is measured per Equation 4. Note that the schedule performance beta must be calculated across multiple different projects, just like there are unique daily values of the stock market. It is obtained by dividing the covariance between a subcontractor's performance in different projects and the projects' (market's) performance by the variance of the projects' performance [46]. Performance here refers to time difference of planned minus actual activity duration or project duration, respectively. But schedule performance of an individual activity relative to its successor or even to the entire project still remains to be explored within this paper.

$$\beta_i = \frac{\mathrm{Cov}(\tilde{r}_i, \tilde{r}_m)}{\mathrm{Var}(\tilde{r}_m)} \quad (1)$$

$$\rho_{i,m} = \frac{\mathrm{Cov}(\tilde{r}_i, \tilde{r}_m)}{\sigma_{\tilde{r}_i} \cdot \sigma_{\tilde{r}_m}} \quad (2)$$

$$\beta_i = \rho_{i,m} \cdot \frac{\sigma_{\tilde{r}_i}}{\sigma_{\tilde{r}_m}} \quad (3)$$

$$\beta_i = \frac{\mathrm{Cov}\left(\tilde{d}_i, \tilde{d}_{Total}\right)}{\mathrm{Var}\left(\tilde{d}_{Total}\right)} \quad (4)$$

Table 2 compares existing methods that have sought to study the relation between the structure of a schedule and the risk of delay. But Tavares *et al.* [30] did not analyze how local activity duration influences total project duration. In their method, network structure and the mean of an individual activity duration were independent variables with respect to the effect on the total project. It is important to note that using the mean value of activity duration misses much useful information instead of using its random durations, as "criticality constellations by whether an activity duration increase (i.e. delay) or decrease (i.e. acceleration) will cause the project duration to increase, decrease, or not be impacted" [47]. Different from those methods, this paper explores the relation between the structure of a schedule as captured through an appropriate proven complexity index and the risk of it being delayed. Whereas beta had measured and aggregated an individual subcontractor's performance across numerous projects compared to the totality of these projects [9], this research determines the correlation coefficient between activity finish times within a schedule. The expected sign (+, 0, -) of this correlation coefficient completely matches with the behavior of an activity within the aforementioned criticality constellations. Note that this study is not limited to examining critical activities (which would be identified initially via a static analysis), but also applies to non-critical activities. Toward the overall goal of understanding the effects of local delays within a network, three **Research Objectives** are set:

1. Create a method to measure the correlation between activity finish times and their underlying schedule structure;
2. Explore the possibility of incurring ripple effects by systematically examining the structure of network schedules;
3. Simulate and study a benchmark schedule to derive practical suggestions for delay avoidance and delay analysis.

Table 2. Comparison of global and local schedule performance methods

Method	Independent variable(s)		Dependent variable(s)
	Network indices	Individual activity effect	Total project effect
Tavares *et al.* [30]	Morphology I_1 to I_6	Activity duration (mean value)	Total duration, μ, δ, $Q_{0.05}$, $Q_{0.95}$
Beta by Thompson *et al.* [35]	Restrictiveness estimator (RT)	Beta (based on duration)	
Method of this paper	Reachability matrix	Correlation coefficient matrix (based on finish time)	

3. Methodology

3.1. Algorithm Development

Taking the correlation coefficient index, which is similar to beta but can be used within a schedule (not between multiple ones), this paper explores the ripple effect that is caused by network structure. It does so by analyzing two matrices; the reachability matrix for capturing the entire relevant information about the network structure, and the correlation coefficient matrix (based on activity finish time) for measuring the ripple effect within a schedule. Figure 1 shows the flowchart of the methodology, which has three modules; the critical path method (CPM) module, the schedule structure module, and the output visualization module. First the CPM module collects the basic schedule input data including activity names, relations and their type (finish-to-start (FTS), start-to-start (STS), finish-to-finish (FTF), or start-to-finish (STF)), and probability distribution (e.g. Normal, Beta, Exponential, Triangular, Uniform, etc.) for each activity duration. Then a Monte Carlo simulation runs many repetitions (e.g. 1000) to generate datasets of randomized durations for all activities to allow examining their behavior statistically. Using the static critical path method (CPM), the earliest finish (EF) of each activity is calculated for each recorded simulation run. The last step in this module is creating the correlation coefficient matrix for said finishes. A correlation coefficient between any two different activities is calculated per Equation 5, no matter whether they are actually connected within the network. As this correlation coefficient matrix is symmetric around its descending diagonal [48], for brevity only upper triangular elements are listed in the remainder of this paper. Its element ρ_{ij} is the correlation coefficient of activities *i* and *j*.

$$\rho_{EF_i, EF_j} = \frac{\mathrm{cov}\left(EF_i, EF_j\right)}{\sigma_{EF_i}\sigma_{EF_j}} \quad (5)$$

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Due to the fact that correlation does not imply causation, element values do not mean that causative relations exist between those activities. But within a schedule, a sequential relationship clearly implies causality from predecessors to successors. Therefore the schedule structure module calculates the reachability matrix to capture the more narrow causative relations within a schedule. The reachability matrix($R = [r_{ij}]_{n\times n}$ is an n by n matrix, where n is the number of activities and $r_{ij} = 1$ if activity i and j are reachable (connected via a directional path), else $r_{ij} = 0$ [49]. Of course, an activity on node (AON) network graph could be generated using the reachability information in this module [50].

Taking the element-by-element product of both matrices yields information on the correlation coefficient between two researchable activities within a schedule: Element $\rho_{ij} \bullet r_{ij}$ in the product matrix is the correlation coefficient of activities i and j if (and only if) they are directly reachable, else $\rho_{ij} \bullet r_{ij} = 0$. Finally the output visualization module displays two pieces of information: A 3D profile is plotted whose two axis dimensions are activity names (same as in the product matrix), while the third dimension is the correlation coefficient between said pair of connected activities. A ripple effect may be seen in this 3D figure. Second, the crucial path(s) and activities can be highlighted to retrace the causes of a potential ripple effect. This new approach as organized in Figure 1 fulfills **Research Objective 1**.

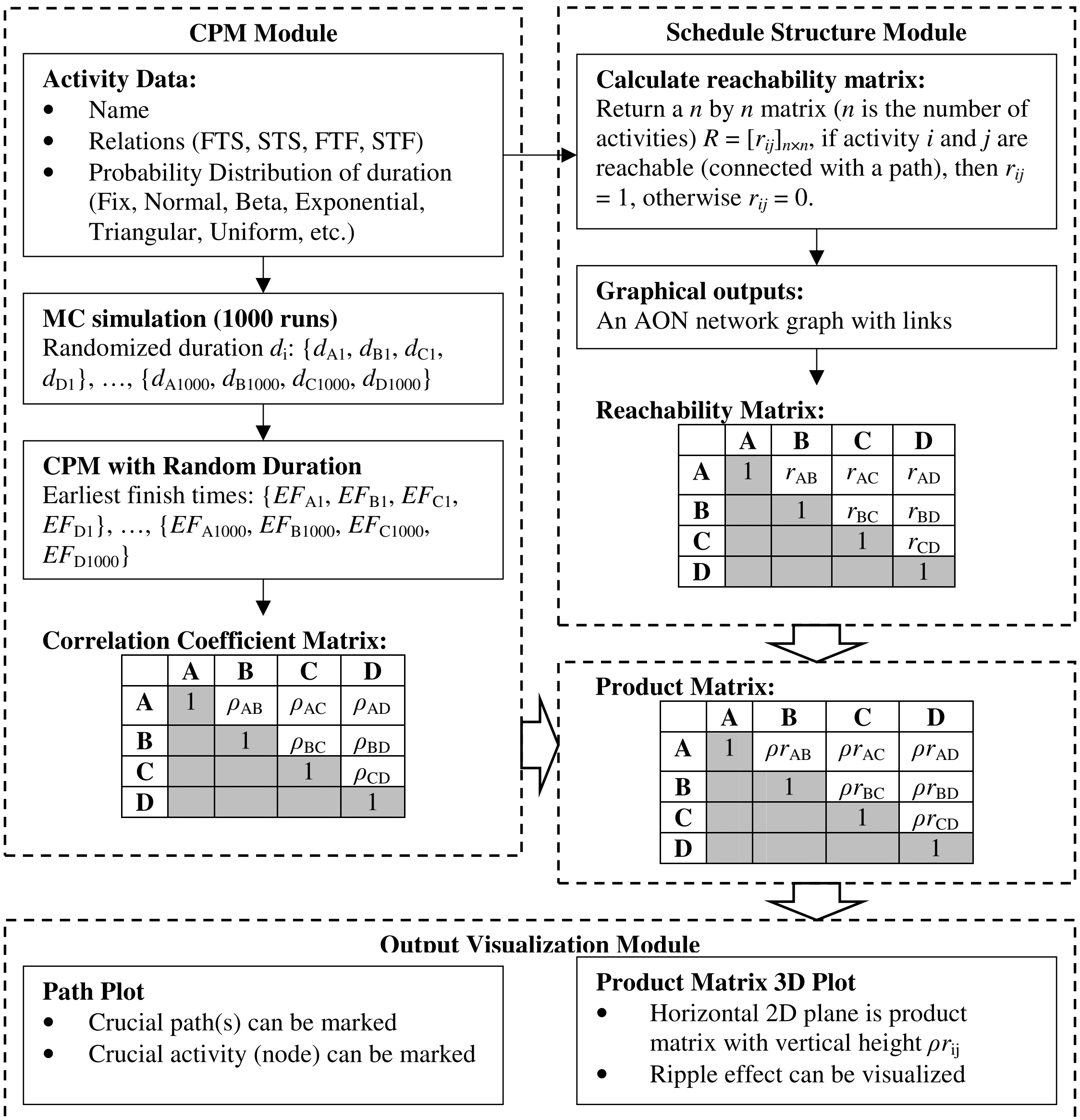

Figure 1: Methodology Flowchart

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3.2. Simulation Experiments

To explore the mathematical behavior of the product matrix, test schedules with six activities that are linked in various ways are used for experimentation. These six activities receive different probability density functions (PDF) as Figure 2 shows. Figure 3a shows the simplest dependency – purely sequential – with a dummy source and sink (schedule #1), where critical activities (CI ≠ 0) are plotted with thick frame and *crucial activities* (newly defined as CI · $\Delta\rho_{ij} \geqslant 0.1$) are plotted in gray. Since element $\rho_{ij} \bullet r_{ij}$ in the product matrix gives the correlation coefficient of two connected activities *i* and *j*, this value inherits all correlation coefficients between activity *i* and its predecessors, plus its own correlation. Thus correlation coefficient ρ_{ij} is the cumulative correlation coefficient of all predecessors of *i* plus its own correlation coefficient per Equation 6. Note that the correlation coefficient values in the last matrix column increase. Hence the dark square in the 3D profile of the product matrix in Figure 3b grows from activity 1 to 6; this cumulative growth is the *ripple effect*. Equation 7 gives the noncumulative correlation coefficient $\Delta\rho_{ij}$ between two reachable activities' finish time. Figure 3b shows these correlation coefficients of individual activities without this inherited ripple effect. The sum of all activities' noncumulative correlation coefficients equals one, which is intuitively correct for sequential schedules and allows deriving Equation 8: The sum of all noncumulative correlation coefficient values multiplied by their criticality indices (CI) must equal one. Equation 8 has two cases; CI = 1 versus a fractional 1 > CI > 0, because for CI = 1 activities, the count of runs where CI ≠ 0 is equal to the total simulation runs *n*. But for 1 > CI > 0 activities, n_{i} is the count of activity *i* being critical among *n* runs. Thus in the fractional case, before summation each noncumulative correlation coefficient $\Delta\rho_{ij}$ is first multiplied by n_{i} / n, which is CI_i itself.

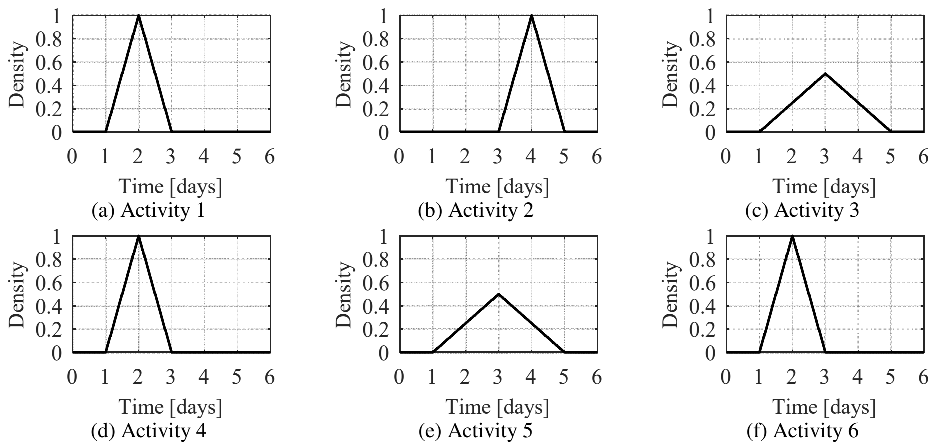
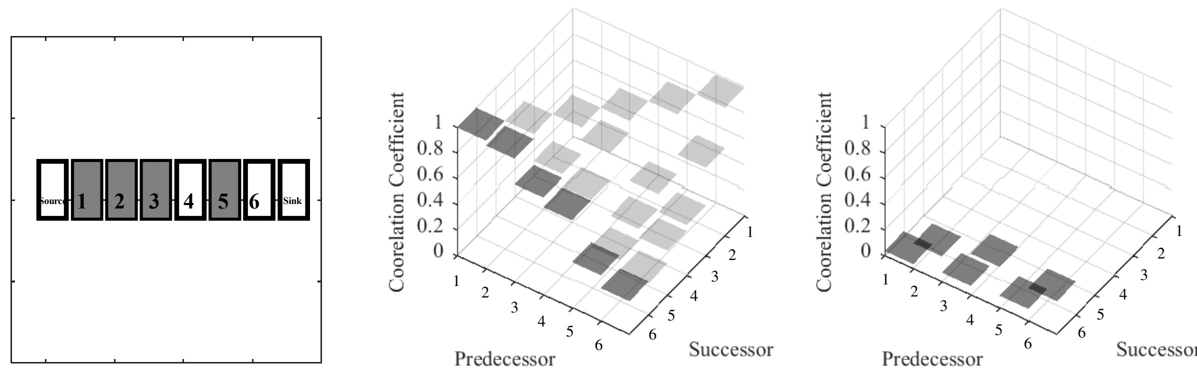


Figure. 2. PDF Profiles for Six Activities

$$\left[\rho_{EF_i, EF_j}\right]_{6\times 6} = \begin{bmatrix} 1 & 0.686 & 0.393 & 0.347 & 0.249 & 0.262 \\ 0 & 1 & 0.533 & 0.414 & 0.326 & 0.362 \\ 0 & 0 & 1 & 0.906 & 0.692 & 0.687 \\ 0 & 0 & 0 & 1 & 0.791 & 0.761 \\ 0 & 0 & 0 & 0 & 1 & 0.962 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

$$\left[\Delta\rho_{EF_i, EF_j}\right]_{6\times 6} = \begin{bmatrix} 1 & 0.686 & 0.393 & 0.347 & 0.249 & 0.262 \\ 0 & 0.314 & 0.140 & 0.067 & 0.077 & 0.100 \\ 0 & 0 & 0.467 & 0.492 & 0.366 & 0.325 \\ 0 & 0 & 0 & 0.094 & 0.099 & 0.074 \\ 0 & 0 & 0 & 0 & 0.209 & 0.201 \\ 0 & 0 & 0 & 0 & 0 & 0.038 \end{bmatrix} \tag{7}$$

$$\sum_{i=1}^{n} \left(\Delta\rho_{EF_i, EF_j} \cdot CI_{ij}\right) = 1 \tag{8}$$



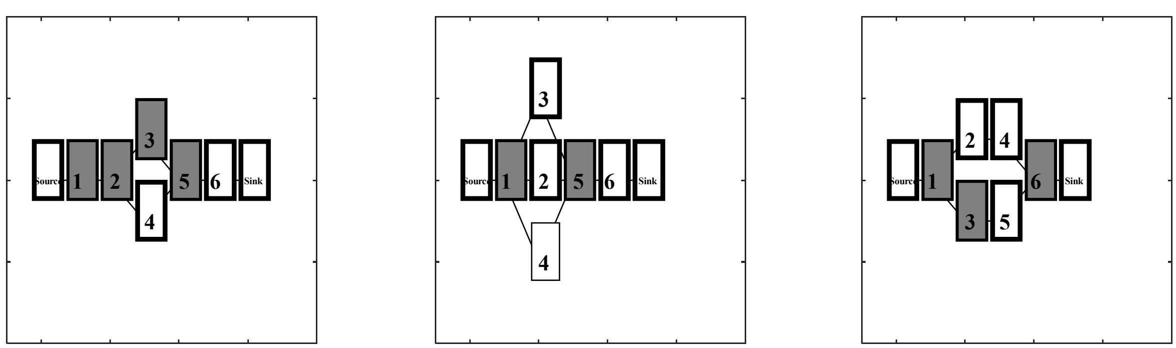
(a) Network Graph (Schedule #1) (b) Cumulative Product Matrix Profile (c) Noncumulative Product Matrix Profile

Figure. 3. Correlation Coefficient Profiles for Schedule #1

To verify Equation 8, noncumulative correlation coefficients $\Delta\rho_{ij}$ are calculated for the networks of Figures 4a-4c (schedules #2-#4) and listed as Table 3 columns along CI and CI · $\Delta\rho_{ij}$ values for all combinations. Note, importantly, that if a critical activity has multiple predecessors (e.g. activity 5 in Figure 4b), its CI = 1 must be split into fractional CI cases for CI of each predecessor (e.g. split CI = 1 of activity 5 into 0.83 and 0.17 for its predecessors). The sum of CI · $\Delta\rho_{ij}$ for all activities will always equal 1 in all schedules, which verifies Equation 8. Observations are as follows:

1. An activity with a large CI · $\Delta\rho_{ij}$ is defined as being *crucial*, which means that the contribution of this activity to the total project performance is rather large. Note the criteria for cruciality can be set subjectively. For example, per Figure 4 and Table 3, ⩾ 0.1 in schedule #2, ⩾ 0.3 in schedule #3, and ⩾ 0.1 in schedule #4, respectively .
2. An activity contributes the value CI · $\Delta\rho_{ij}$ to a project delay of 1 day, e.g. 0.117 days for activity 2 in schedule #2;
3. The sum of CI · $\Delta\rho_{ij}$ values of activities within the same path is the potential contribution of said path toward an assumed project delay of 1 day, e.g. 0.06375 + 0.04794 = 0.11169 days for activities 2 and 4 in schedule #4;
4. A negative CI · $\Delta\rho_{ij}$ value usually occurs in the less critical path (with small CI ≠ 0), e.g. -0.187 days for activity 3 in schedule #3. This phenomenon stems from the negative ρ_{ij} of the less critical activity, because its EF typically does not have the same trend as the EF of its critical predecessor. It therefore acts desirably against a project delay of 1 day, in that a negative contribution is its buffering capacity that can locally absorb such delays.

Local delays have a cumulative, structure-dependent, quantifiable impact as ripple effects on project performance. Having explored these network behaviors with experiments on the example schedules fulfills **Research Objective 2**.



(a) Schedule #2 (b) Schedule #3 (c) Schedule #4

Figure. 4. Network Graphs of Schedules #2, #3, and #4

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Table 3. Results Summary for Schedules #2, #3, and #4

Schedule	#2			#3			#4		
Activity	CI	$\Delta\rho_{ij}$	CI · $\Delta\rho_{ij}$	CI	$\Delta\rho_{ij}$	CI · $\Delta\rho_{ij}$	CI	$\Delta\rho_{ij}$	CI · $\Delta\rho_{ij}$
1	1	0.280	0.280	1	0.475	0.475	1	0.225	0.225
2	1	0.117	0.117	0.85	0.022	0.0187	0.51	0.125	0.06375
3	0.83	0.290	0.2407	0.15	-0.187	-0.02805	0.49	0.335	0.16415
4	0.17	0.031	0.00527	0	-0.144	0	0.51	0.094	0.04794
5	1 =			1 =			0.49	0.058	0.02842
	0.83	0.248	0.20584	*0.85*	0.412	0.3502			
	0.17	0.507	0.08619	*0.15*	0.621	0.09315			
				0	0.578	0			
6	1	0.065	0.065	1	0.091	0.091	1 =		
							0.51	0.556	0.28356
							0.49	0.382	0.18718
Sum	N/A	N/A	1.0000	N/A	N/A	1.0000	N/A	N/A	1.0000

4. Validation

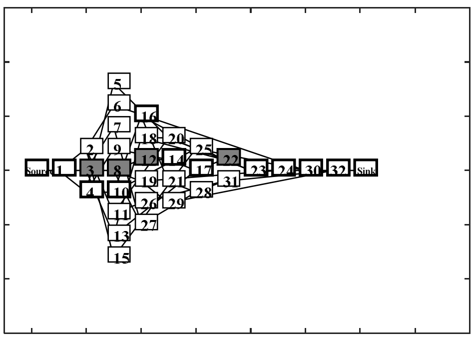

Figure. 5. Network Graph for Schedule J30

A benchmark schedule (J30) from the Project Scheduling Problem Library (PSPLIB) [51] is used to assess the robustness of Equation 8 in a larger, more complex network. Figures 5 shows it with crucial activities in gray. Per Table 4, the sum of CI · $\Delta\rho_{ij}$ for all activities is 1.0000. All three observations still exist in this complex schedule.

If a critical activity has multiple predecessors (e.g. 22 in Table 4), then its CI is split into fractions 0.78 and 0.22 to consider the CI of its predecessors 16 and 17. Practical suggestions can be derived:

Delay avoidance:

1. Focus on those activities with larger CI · $\Delta\rho_{ij}$, because they potentially contribute more toward a project delay;
2. Focus on paths with larger CI · $\Delta\rho_{ij}$, because they carry a higher risk of propagating delays and are 'crucial';
3. In the order of importance, focus first on managing the larger CI · $\Delta\rho_{ij}$ > smaller CI · $\Delta\rho_{ij}$ > negative CI · $\Delta\rho_{ij}$;
4. Create less sequential paths in a schedule, which can protect the project duration. The CI · $\Delta\rho_{ij}$ provide a good indicator to select which path should be rescheduled toward being more concurrent. In sequence of increasing utility, this means larger CI · $\Delta\rho_{ij}$ (more sequential) > smaller CI · $\Delta\rho_{ij}$ > negative CI · $\Delta\rho_{ij}$ (more concurrent).

Table 4. Result Summary for Schedule J30

Activity	CI	$\Delta\rho_{ij}$	CI · $\Delta\rho_{ij}$	Activity	CI	$\Delta\rho_{ij}$	CI · $\Delta\rho_{ij}$	Activity	CI	$\Delta\rho_{ij}$	CI · $\Delta\rho_{ij}$	Activity	CI	$\Delta\rho_{ij}$	CI · $\Delta\rho_{ij}$
1	1	0	0	8	0.78	0.163	0.12714	17	0.78	0.019	0.01482	24	1	0.036	0.036
2	0	0.144	0	9	0	*	0	18	0	*	0	25	0	*	0
3	0.78	0.431	0.33618	10	0.22	0.054	0.01188	19	0	*	0	26	0	*	0
4	0.22	0.008	0.00176	11	0	*	0	20	0	*	0	27	0	*	0
5	0	*	0	12	0.78	0.138	0.10764	21	0	*	0	28	0	*	0
6	0	*	0	13	0	*	0	22	1=			29	0	*	0
				14	0.78	0.021	0.01638		*0.78*	0.895	0.1969	30	1	0.015	0.015
				15	0	*	0		*0.22*	0.162	0.12636	31	0	*	0
7	0	*	0	16	0.22	-0.023	-0.00506	23	1	0.015	0.015	32	1	0	0
												Sum	N/A	N/A	1.0000

Delay analysis:

1. It is possible to measure the magnitude of the contribution of each activity toward a project delay of 1 day;

2. Critical activities at a merge merit special attention. Although its CI is 1, it could be split into fractional CIs. This has potential to be applied for assigning delay responsibility to concurrent activities in shares of CI · $\Delta\rho_{ij}$;
3. Activities with negative CI · $\Delta\rho_{ij}$ arise because of a negative ρ_{ij} for the less critical activity. This phenomenon occurs, because most of the time the less critical activity is noncritical (does not affect the project finish).

Having summarized practical suggestions for delay avoidance and delay analysis fulfills **Research Objective 3**.

5. Conclusions

Construction schedules have lacked local performance indices to measure the potential contributions of individual activities to the total project finish. The product of the elements of correlation coefficient and reachability matrices has filled this gap. But a schedule has its unique network structure that determines not just criticality, but also the new *cruciality*. Therefore this paper has developed a new methodology for performance measurement that considers the network structure and correlation coefficient between two reachable activities' finish time within a schedule. Cumulative and noncumulative forms of product matrices have been plotted in 3D profiles. The former lists the ripple effect in its last column; the latter lists the noncumulative correlation coefficient values multiplied by their corresponding criticality index to gain their *cruciality* CI · $\Delta\rho_{ij}$ and must sum to one. Activities with nonzero CI are critical, but not all of them are crucial (with larger CI · $\Delta\rho_{ij}$). Crucial means the contribution of an individual activity to the total project performance is relatively large. The meaning of individual CI · $\Delta\rho_{ij}$ values within a schedule has been studied by testing several examples. Applying it to a more complex schedule from PSPLIB, the robustness of the results has been validated. Practical suggestions for delay avoidance and delay analysis have been derived from these observations and explained. They include focusing on more crucial activities and the paths that contain them, and potentially reworking the structure toward a more concurrent one that may help avoid or reduce delay impacts.

Acknowledgements

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A Framework to Evaluate the Resilience of Hospital Networks

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Abstract

This paper puts forward as framework to evaluate the resilience of hospital networks. Natural and man-made disasters can lead to significant social, economic and socioeconomic losses. Enhancing the resilience of communities in face of disasters can reduce these losses. Resilience is the ability of a system to resist, absorb and eliminate the effects of a hazard and to resume its performance at the desired level at an acceptable time. The resilience of hospital network in a community is among the most critical factors in reducing the losses caused by disasters. However, in many situations, the failure of one or multiple hospitals in a network reduces the overall capacity of the network, forces the movement of patients from one hospital to another, and leads to significant losses. There is need for an appropriate index that can be utilized in order to evaluate and measure the resilience of hospital network and identify the opportunities for enhancing its resilience. In this paper, a hospital network resilience index is presented. A simulation framework is also introduced in order to measure the resilience of hospital network under uncertainties about the magnitude and consequence of hazard, response of various components of hospitals, and the performance of transportation network and lifelines such as electricity network. The proposed framework can be utilized in order to evaluate the impact of lack of hospital network resilience on its capacity to treat the casualties of a disaster, the movement of patients from one hospital to another as a result of inability of a hospital to provide services, and the subsequent losses.

Keywords: hospital network; resilience index; simulation; uncertainty.

1. Introduction

Natural and human disasters have always existed and caused a lot of damage. Among the most devastating disasters are earthquakes. Earthquakes often damage vulnerable infrastructures and cause casualties in most regions frequently. For example, the 2010 M7.0 Haiti Earthquake left more than Two hundred thirty thousand people dead [6].

Measures can be taken to reduce these injuries and losses, including providing proper medical services after an accident [5]. Hospitals play a critical role as they treat the earthquake casualties and prevent the death toll from rising. They are faced with increasing demand after an incident, and on the other hand they must be able to serve the injured people [9]. Hospitals must save their performance in the face of earthquake (i.e., they should not sustain damage or if damaged they should resume their services in an optimal manner) [3]. This is the fundamental characteristics of a resilient hospital. Hospital disaster resilience is the ability of the hospital to respond, resist and absorb the disaster effects to provide health care, and then return to the basic or acceptable level of service [11]. In many cases, when there are multiple hospitals in an earthquake affected region, the patients are moved from hospitals that are damaged or overloaded to the one that is capable of accepting more patients. Therefore, although some hospitals may fail or collapse, the network might be able to handle the surge in the demand.

Hospital network managers and planners need to investigate the impact of an earthquake on the individual hospitals and the network as a whole in order to determine the resilience of healthcare system in a region and plan for mitigation strategies.

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Recent disasters have shown that various areas, such as human resource management, planning, hospital integration, and the establishment of strong and coordinated relationships between different structures, are needed [7]. There are not enough research in hospital network resilience field. Single hospital resilience is studied in [1], [2], [4], [7] and [8] but last research studies focus only on one hospital and there is no indicator for a multi-hospital system review taking into account the interactions of system components. This is while we know that components affect each other in a system. For example, a lack of capacity of a hospital affects the performance of other hospitals and, as a result, reduces overall resilience. Therefore, the robustness of hospital network must be enhanced**.**

The objectives of this project are introduction of an appropriate index to estimate the probability of hospital network resilience, called the Hospital Network Resilience Index (HNRI) and providing a tool for simulating the performance of hospital network after an accident, taking into account uncertainty. Final objective is introducing a suitable model using HNRI to analyze the problem of making decision about hospital location and capacity measurement.

Decision-makers in this field need to first have an index to measure the resilience of the treatment network, and then they can be involved in investing in the construction of a new hospital or increasing the capacity and rehabilitation of the current hospitals with a model. In this project, first, the effect of reducing the capacity of a member of the treatment network on the entire network should be estimated and the capacity of the post-incident treatment network should be determined in general. Then, a solution is given to improve the overall network performance by adding a new unit, or increasing the resilience and capacity of the current units. If a new unit should be built, its position and capacity will also be determined.

2. Research Background

Due to the possibility of disasters and accidents such as earthquakes, it is necessary to take steps to deal with its destructive effects. One of these measures is to increase the resilience of the hospital networks taking into account their interactions in the system. Some studies have been done about this problem. Achour et al. [1] detected the effect of different factors on the level of resilience by using a questionnaire from different hospitals. The six factors that were more effective than the others are indicated by xi in relation 1 as follows:
electricity (x1), gas supply (x2), water supply (x3), landline telecommunication (x4), mobile phone (x5) and Personal Handy-phone System (PHS phone) (x6).

$$y= -1.36x_1 +0.163\ x_2 +2.059\ x_3 -0.067\ x_4 +0.043\ x_5 +1.27\ x_6 +0.123 \quad (1)$$

Cimellaro et al., [4] first, introduced the function parameter for a hospital. Figure 1 shows the process of its change after the incident. Then, this parameter is formulated using the waiting time for one hospital and using the number of patients in queue for hospital networks.

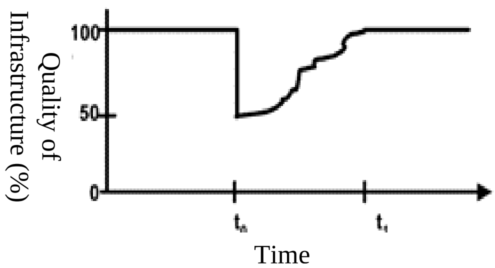

Fig. 1. Changes in the quality of infrastructure performance [4].

Also, Arcidiacono et al. [2] have created a software for calculating the resilience of each section of society. The software is developed using the relationships in their last papers. The inputs of the proposed system are related to the relevant structure information, such as the location and physical parameters of the infrastructure and the failure parameters. Using this system, the resilience of each of the structures is analyzed, and then, their weighted average results in the resilience of that section of society. This review is done regardless of uncertainty.

Another study was done by Cimellaro et al. [4] that functionality is considered to be a function of quantitative and qualitative functionality for the calculation of resilience according to the following relationship. Where T_{lc} is the control time (usually life span of the system) and t_0 is the time to start observing.

$$R = \int_{t0}^{t0+Tlc} \frac{Q(t)}{Tlc}\, dt \quad (2)$$

Another study was conducted by Amy [7] to assess the preparedness of hospitals in Los Angeles. Verification of this survey study was conducted by on-site inspections. The number of hospitals surveyed in this study was forty five.

Khanmohammadi and Kashani [8] simulated events after an earthquake using Discrete Event Simulation and characterized the hospital behavior as well as the amount of post-incident demand while taking into account multiple uncertainties such as the degree of damage and the recovery process. Using their proposed model, they determined the impact of the patients' waiting time on their mortality rate. Also, the effects of the hazard and prolongation of waiting time on the structure of the society's economy are considered. Then a proper decision is made to increase the resilience of the hospitals.

Studies have shown that previous research has only looked at an isolated hospital and does not consider the effects of hospitals in a network as components of a system. The way a component acts affects the whole system. Post-incident events also are not simulated and optimized at the same time. Therefore, it is necessary to simulate events after the earthquake, to predict events in the network and then to optimize it.

3. Model

To quantify hospital network resilience, a framework has been designed, consisting of several models that are used step-by-step in the order shown in the figure below:

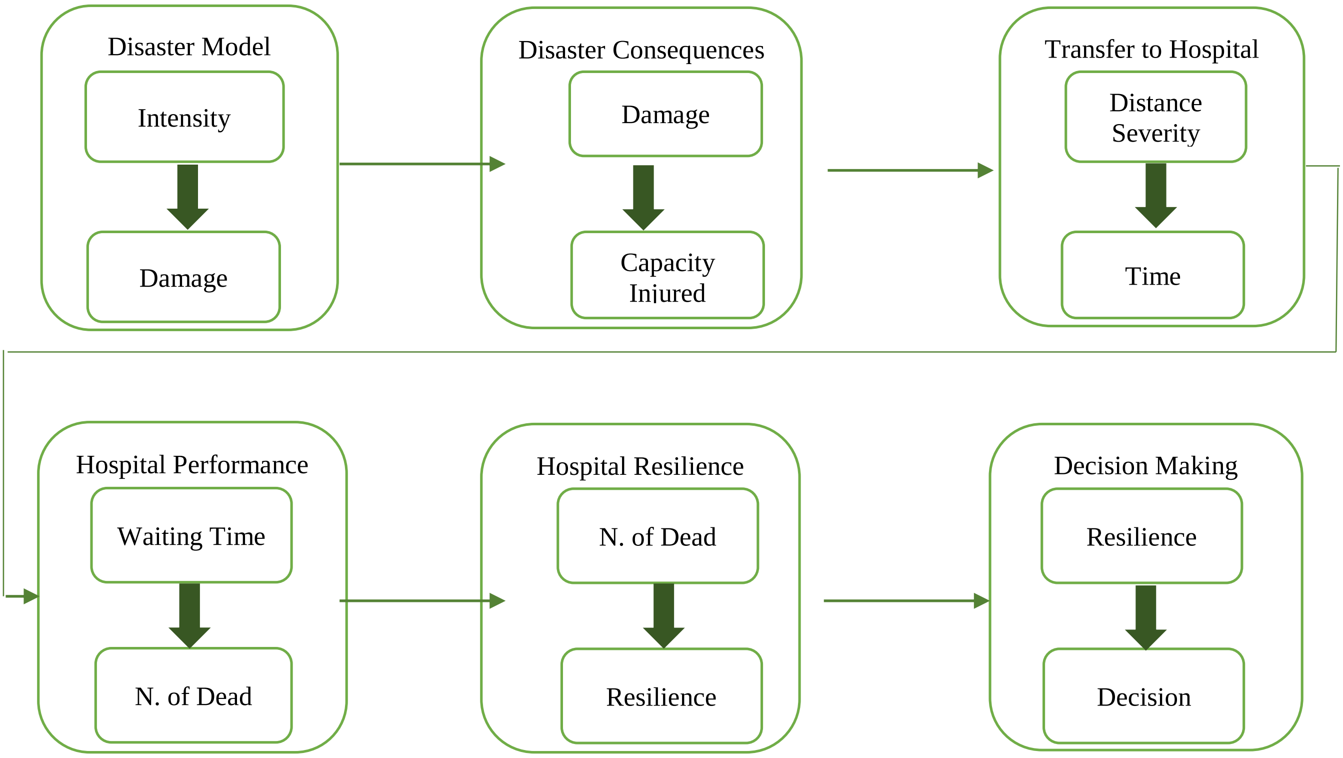

Fig. 2. Framework to calculate hospital network resilience.

Two of the most important components of the research are hospital accessibility and capacity. They influence patients' waiting time. Patients' waiting time determines the patients' situation in every moment. Other components are intensity of the hazard, quality of buildings and population of the region. These three components affect number of injured population. We also consider number of ambulances, road condition and traffic condition as effective components of time on way to hospital. Finally, quality of hospital performance is important in reducing waiting time and number of dead people. Resilience can be measured based on total dead number.

4. Example

Time and intensity of the model can be generated randomly but we considered that before the implementation of the earthquake model, an earthquake with assumed intensity and time had occurred. So earthquake intensity and its damage is known. Scenario sampling is used in this example. Since we need the number of wounded and the dead to run the model, the required initial data are obtained from Northridge earthquake in 1994. According to

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reports from Northridge earthquake, it can be concluded that the number of fatality in this earthquake is 33. The total population during the earthquake is estimated 8863164 people [10]. Then, the number of people in other level of injury can be obtained from HAZUS manual.

According to the HAZUS technical manual, the injured people are divided into four groups according to severity of injury, as shown in the table below [12]. Severity 4 shows fatality and from 1 to 3, severity becomes more. In table 2, the number of each group is calculated based on reports from Northridge earthquake. It is assumed that just a part of society is injured.

Table 1. Injury severity scale based on the HAZUS technical manual [12].

Injury Severity Scale	Ratio
Severity1	0.58
Severity2	0.10
Severity3	0.02
Severity4	0.30

Table 2. Number of each group of severity calculated based on reports from Northridge earthquake.

Injury Severity Scale	Ratio
Severity1	64
Severity2	11
Severity3	3
Severity4	33

Model is created in AnyLogic simulation software. It is assumed a lag between patients' arrivals because of the transportation network inefficiency. The standard deviation of the time between arrivals is high relative to mean because the after-incident condition of roads is uncertain. Other assumptions are:

- Three hospitals are in the region.
- Type 1 of severity can go three hospitals based on his condition.
- Type 2 of severity can go hospital two and three.
- Type 3 of severity first goes to hospital three. If the queue is long, patients will die.
- Type 4 of severity get immediate help in their initial place.
- If the queue of hospital one is long, patients will go to hospital two or will die.
- If the queue of hospital two is long, patients will go to hospital three or will die.
- Every hospital has doctor, nurse and triage nurse.

After running the model, the results are shown in figure3 and table3. Fig. 3.a. and 3.b. show number of dead people before and after earthquake. Fig. 3.c. and 3.d. show number of transferred patient before and after earthquake. The numbers after disaster are more than before it. It is obvious because the capacity of hospitals decrease and the number of patients increase. According to fig. 3.e. and 3.f., waiting time of hospital network dramatically increases after disaster. It can be understood that the resilience of the hospital network is not appropriate because number of dead and transferred patients are high in comparison to the total number of injured people. Waiting time of hospital one is also higher than others so it withstands more pressure. It can be concluded that one of the proposed suggestion for improvement of resilience is establishing a hospital around the hospital one. The advantage of the decrease in number of dead and the cost of building a new hospital or increasing its serviceability can be compared and the best decision can be made based on it. Fig. 3.g. shows the randomness of treatment time. It shows the uncertainty of after-incident condition.

Table 3. Average waiting time in each hospital.

Parameter	Result
Average Waiting Time of hospital one	17.24 min
Average Waiting Time of hospital two	13.10 min
Average Waiting Time of hospital three	10.56 min

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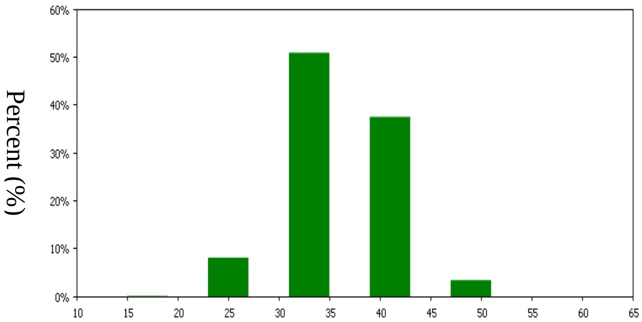
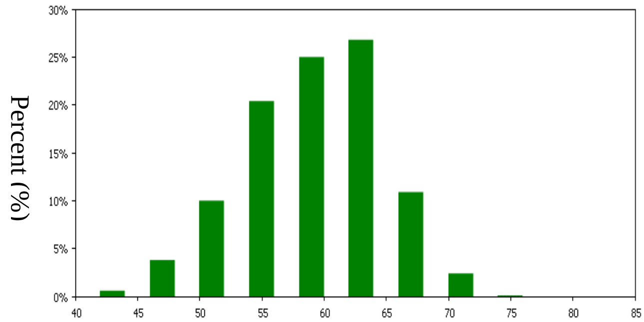
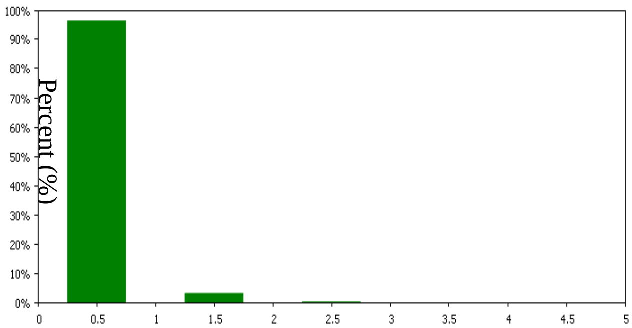


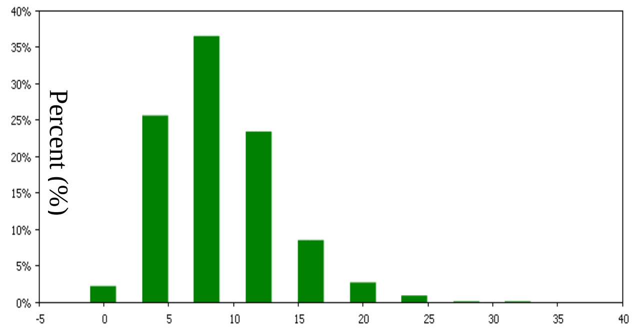
(a)
Number of Dead People
(Before Earthquake)



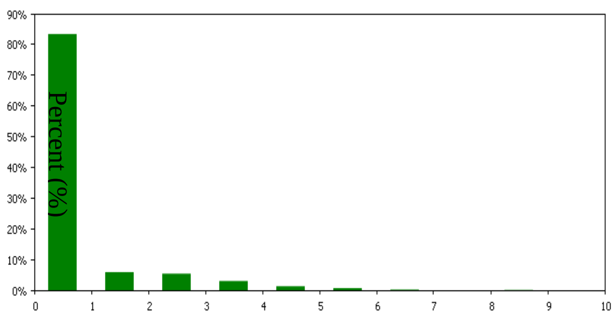
(b)
Number of Dead People
(After Earthquake)



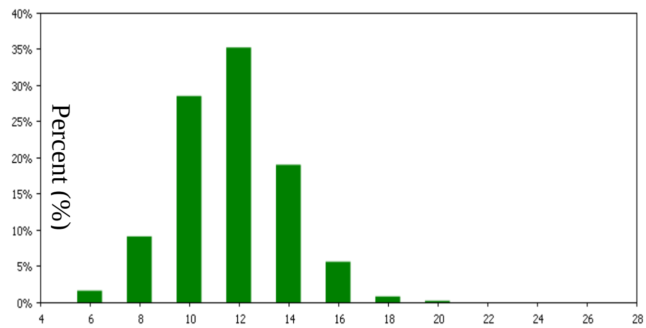
(c)
Number of Transferred Patient
(Before Earthquake)



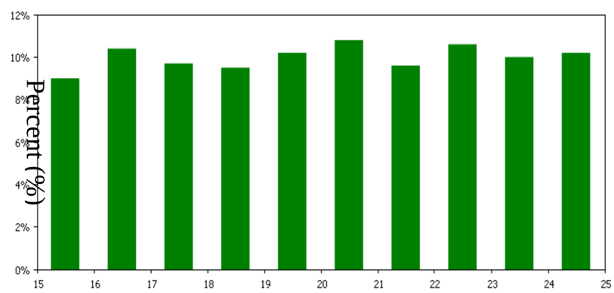
(d)
Number of Transferred Patient
(After Earthquake)



(e)
Network Waiting Time (min)
(Before Earthquake)



(f)
Network Waiting Time (min)
(After Earthquake)



(g)
Random Treatment Time (min)

Fig. 3. a) Number of dead people before earthquake, b) Number of dead people after earthquake, c) Number of transferred patient before earthquake, d) Number of transferred patient after earthquake, e) Network waiting time before earthquake (min), f) Network waiting time after earthquake (min), g) Random treatment time (min).

5. Conclusion

This paper puts forward as framework to evaluate the resilience of hospital networks. The resilience of hospital network in a community is among the most critical factors in reducing the losses caused by disasters. There is need for an appropriate index that can be utilized in order to evaluate and measure the resilience of hospital network and identify the opportunities for enhancing its resilience. In this paper, a hospital network resilience index was presented. A simulation framework was also introduced in order to measure the resilience of hospital network under uncertainties about the magnitude and consequence of hazard, response of various components of hospitals, and the performance of transportation network and lifelines such as electricity network.

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A Probabilistic Model for Evaluating the Impact of Prepositioning of Rescue Centers of Earthquake Consequence Management

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Abstract

This study puts forward a probabilistic model for evaluating the impact of the prepositioning of rescue centers on earthquake consequence management operations. In urban areas, a disaster such as an earthquake can lead to severe casualties. Failure to provide timely medical services can increase the number of earthquake fatalities. Rescue teams can play a critical role in reducing the number of earthquake fatalities by helping those injured in the shortest possible time. In this regard, the placement of rescue centers is critically important. A probabilistic model is needed in order to evaluate the impact of prepositioning of rescue centers on earthquake consequence management operations. The proposed probabilistic model estimates the number and the distribution of the earthquake casualties based on the severity and time of the earthquake as well as the vulnerability of the buildings in the affected area. It also takes into account the expected time spent on rescuing individuals from each affected building as well as the expected time each rescue team spends traveling from one affected building to another. The model also takes into account the consequences of delays in rescuing the earthquake casualties in terms of loss of life and exacerbated injuries, and characterizes these consequences in monetary terms. This probabilistic model can be utilized in order to determine whether the existing rescue centers are appropriately-positioned and adequate, and, if not, identify the candidate positions for establishing new rescue centers before disaster occurrence.

Keywords: uncertainty; healthcare; earthquake; location analysis; rescue center.Introduction.

1. Introduction

Since 1970, more than 10,000 natural disasters have occurred across the globe, causing over the $2 trillion in estimated damage [1]. In response to a natural disaster, varieties of efforts are taken in order to limit the consequent social and socioeconomic losses by providing relief to victims and reducing the number of casualties. Emergency medical service (EMS) facilities play a unique and critical role in the delivery of services to earthquake casualties [2-4].

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Natural disasters such as earthquakes often damage civil infrastructures systems. These damages negatively affect the ability of infrastructure systems to function appropriately. In case of the transportation infrastructure system, the damages caused by natural disasters such as earthquake can disrupt the movement of emergency vehicles that support the disaster response operations [5]. In addition to the potential disruptions in transportation, other challenges such as the lack of information due to the failure of communication systems augments the challenges of delivering relief to the victims in a timely manner [6-11]. Appropriate pre-positioning of the resources, particularly the rescue centres, can increase the effectiveness of disaster response operations and contribute to the reduction of the casualties [12]. The geographical distribution of relief and rescue centres affect the performance of relief and rescue efforts, which in turn affects the response time and costs incurred throughout the operation.

Several past studies have investigated the positioning of the assets used in emergency and rescue operations. For instance, Jia et al. [13] present models to determine the optimal location of EMS facilities under major emergencies such as bioterrorist attacks. Maleki et al., [14] formulate two models to assign ambulances to calls using mixed integer programming. The objective of the first model is to minimize the total travel time of ambulances. The objective of the second model is to minimize the maximum time travelled by ambulances. Simultaneous application of both models leads to a plan that reduces the travel time and improves the area covered by the ambulances. Naoum-Sawaya and Elhedhli [15] present a two-stage stochastic optimization model for the ambulance relocation problem that minimizes the number of relocations and maximizes coverage. Other methods such as queuing theory [16] and hypercube models [17-18], dynamic programming [19] have also been applied in order to investigate the positioning of the EMS resources. Simulation has also been used in order to analyse the performance of EMS resources following a disaster. Ross [20] examines the various methods of dispatching and their impact on the workload of the call center employees by using simulation. Su and Shih [21] develop a simulation model and evaluate the ambulance service system of Taipei under various staff levels and number of assigned emergency network hospitals. Kozan and Mesken [22] analyse the effects of changing call rates, distribution of workload and personal resources on the call centre efficiency by developing simulation model. Meanwhile, Berchi et al. [23] use simulation approach to estimate the optimal location and number of ambulances for ambulance service system in Italy.

The overview of literature indicates that the existing models for evaluating the performance of EMS assets are subject to a key limitation. Specifically, existing models do not take into account the multiple uncertainties associated with the demand for EMS resources and their operations including the uncertainty about the intensity of the disaster, the number of casualties, the severity of injuries sustained by the victims, the geographical distribution of the victims, the number of available emergency vehicles, and state of the transportation and health infrastructure systems. In order to address the limitation of existing models, this paper presents a simulation model that characterizes the uncertainties mentioned above and can be used in order to evaluate the impact of prepositioning of rescue centres on earthquake consequence management and provide a valuable insights for decision making about the location of rescue canters. By taking into account the multiple sources of uncertainty, the proposed model provides valuable insights that if used within a decision analysis framework, facilitate the development of a better plan for disaster management.

2. Model

The proposed framework simulates the performance of ambulance service systems that are dispatched from rescue centres. This framework contains several integrated models. **Fig. 1.** presents an overview of the proposed framework and its integrated models. In this framework, occurrence time and magnitude of earthquake, population and occupancy ratio of buildings as well as building structure (model building) types affect distribution and number of causalities in each severity level. There are four severity levels of causalities that are demonstrated in Table 1. It should be noted that for each severity type, if medical care is not provided to the patients during a pre-specified period, the severity of their injuries exacerbates. According to the findings of the past studies, for severity 1, this period is 390 minutes after initial trauma. Severity 2 and severity 3 require treatment within 270 and 80 minutes [25-26]. In this study, the survivability time is a function of the severity level and time of arrival to hospital. Transfer time to the hospital itself depending on the condition of the roads, and has been investigated probabilistic. Survivability time is also expressed in random and probable terms.

Table 1: Injury Classification and, Ratio [24]

Injury Severity Scale	Injury Description
Severity 1	Injuries requiring basic medical aid
Severity 2	Injuries requiring medical technology
Severity 3	Injuries that pose an immediate life threatening condition
Severity 4	Instantaneously killed or mortally injured

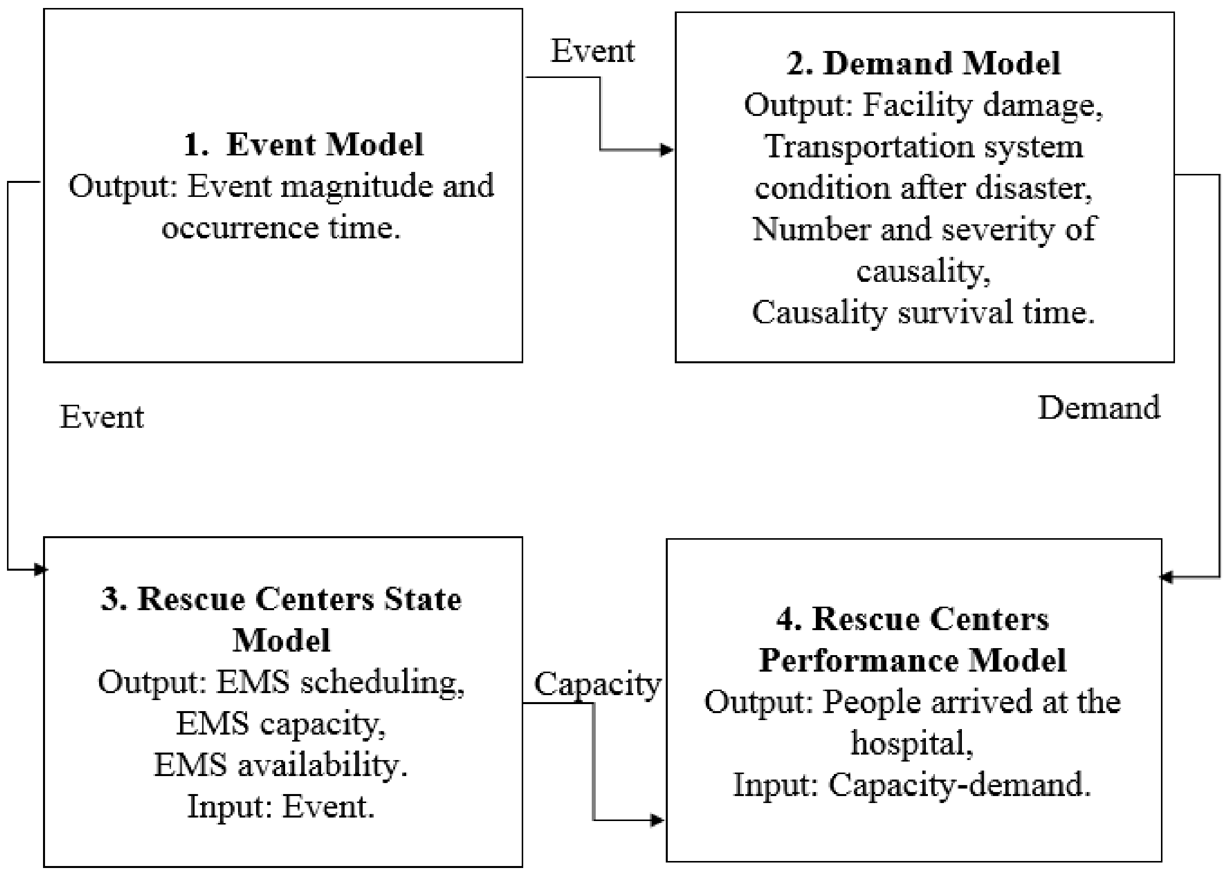

Fig. 1. Interactions among the Stock Models of the Location planning for rescue centres.

In the following, these models are discussed in details.

Event Model

Using this model, the magnitude and time of future earthquakes are generated. To accommodate earthquake magnitude uncertainties, various earthquakes with low to high intensity simulated to capture uncertainty regarding the magnitude of any potential earthquake in the region.

Demand Model

For each scenario, based on the magnitude and time of disaster occurrence, the number of injured and the level of their injuries have been investigated with regard to population density and various types of damage of the five main types of buildings.

Rescue Centres State Model

This model evaluates effect of magnitude and time of disaster occurrence on rescue centres location and EMS units that are dispatched from them.

Rescue Centres Performance Model

Using this model, the post-earthquake serviceability of EMS units is compared against the demand based on the prepositioning station of rescue centres. Potential sites for ambulance's station are chosen with regard to access to the streets, geographical specifications, location of population centres, and proximity to the hospital(s) and final objective is to better distribute EMS units throughout the region.

3. Example

This proposed model is made to the case post-earthquake rescue in a city. The city is assumed to have a hospital. The buildings located in the city are categorized into are five main types. Specific to each class is the vulnerability in face of earthquakes. The seismic vulnerability of the building, the earthquake intensity, and the number of occupants at the time of earthquake are the key determinants of the number of earthquake victims in a building. It is also assumed that there are 10 candidate sites for the prepositioning of the rescue centres. These candidate sites are selected considering factors such as access to the main roads, geographical features, location of population centres, and proximity to hospital(s). Among these candidate sites, the most appropriate must be selected with the objective of improving the distribution of EMS resources from rescue centres throughout the region.

The proposed simulation model was implemented in Any Logic simulation software. In each scenario, time and intensity of earthquake occurrence are different, and resident's numbers in each buildings as well as type of buildings are selected randomly. In each scenario, the location of population centres and the deployment location of rescue centres are selected around the hospital, randomly. For example, fig.2 shows the coverage of population centres and deployment centres for four selected scenarios and table 2 presents distribution of total number of patients with severity 3 that are arrived to hospital for each scenario in 100 iteration, after 24 hours of disaster occurrence, probabilistically.

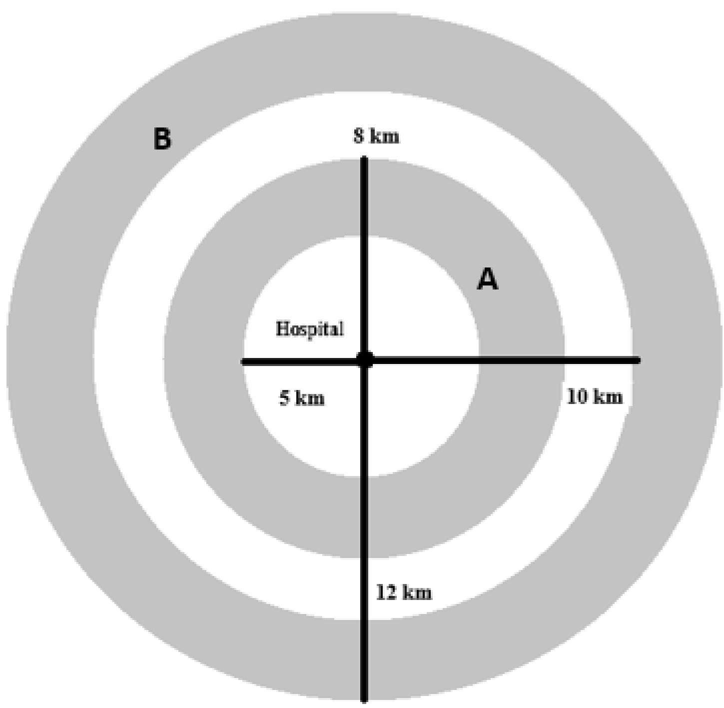

Fig. 2. Candidate points for population centres and rescue centres location.

Table 2. Distribution of total number of patients with severity 3 arrived at the hospital in different scenarios for 100 iterations, after 24 hours.

Rescue center location	Buildings location	No. of severity 3 patients		
A	B	13% 40-44	87% 45-47	
A	A	3% 40-44	95% 45-47	2% 48-52
B	B	36% 40-44	64% 45-47	
B	A	11% 40-44	89% 45-47	

To show effect of location on response time, fig. 3 presents total no. of patients that are arrived in hospital, in term of time. If the distance between two sites is about 5-8 km, they are considered far, and they are considered close if distance between them is 10-12 km.

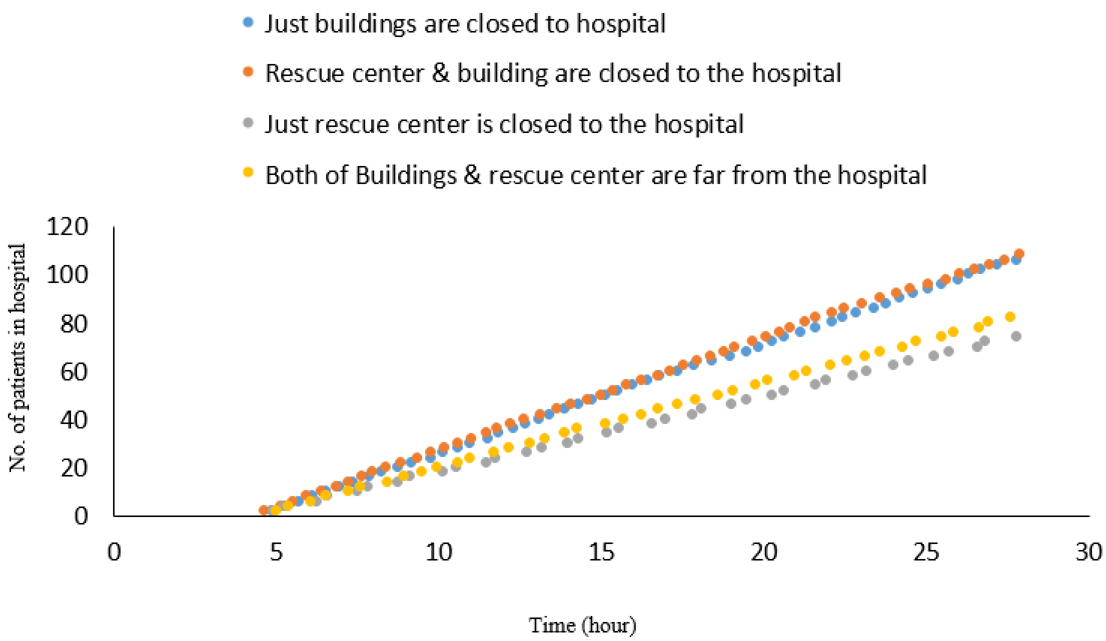

Fig. 3. No. of patients in hospital in term of time.

4. Conclusion

This study presents a probabilistic model for evaluating the impact of the prepositioning of rescue centres in the pre-disaster phase of disaster response operations. Rescue teams can play a critical role in reducing the number of earthquake fatalities by servicing those injured and arriving them to hospital by using ambulances. The more time for receiving medical service, lead to increase the number of earthquake fatalities. The objective is to choose the rescue centres location and then dispatch EMS units from them to maximize the efficiency of the EMS units by decreasing service time for patients. The risk for building is estimated as the multiplication of the (probability) disaster intensity and time of occurrence and the vulnerability of the building structure. In addition, the proposed probabilistic model estimates the number and the distribution of the earthquake casualties based on the severity and time of the earthquake as well as the vulnerability of the buildings in the affected area. It also takes into account the expected time spent on rescuing individuals from each affected building as well as the expected time each rescue team spends traveling from one affected building to another. The model also takes into account the consequences of delays in rescuing the earthquake casualties in terms of loss of life and exacerbated injuries, and characterizes these consequences in monetary terms. This probabilistic model can be utilized in order to determine whether the existing rescue centres are appropriately positioned and adequate, and, if not, identify the candidate positions for establishing new rescue centers before disaster occurrence. This model can be tailored for any EMS system in which location of buildings and hospital are available.

This study shows that the position of individuals towards the hospital has a significant impact on the response time and receiving hospital services. Secondly, the positioning of EMS relative to individuals has a tremendous impact on improving the level of service to patients. The more EMS is closer to the population centres, the more survivors will be. Then, it is necessary to identify the high-risk and congested areas in order to find the appropriate location for EMS stations.

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An investigation of the most waste-prone materials and waste causes in prefabricated steel structure building projects

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Abstract

Prefabrication is the shifting of construction activities from traditional practices, with high level of waste, to industrial processes with minimum waste generation. Therefore, it is considered as one of the major improvements to minimize waste generation in the construction industry. However, the prefabrication process itself is associated with significant amount of material wastage; which increases the total project cost and time with negative environmental impacts. In order to take efficient measures in reducing the amount of waste at source, which is the initial step in waste management, it is essential to identify the most waste-prone materials and investigate the main sources of waste generation. The current paper presents initial findings of an on-going research on development of a process model as well as a decision support tool to predict and manage waste in prefabricated steel structure projects. An investigation has been carried out in collaboration with the Turkish prefabricated steel structure building companies to identify the most waste-prone materials and the main sources of waste generation. A mixed research method incorporating qualitative and quantitative approaches were adopted during the initial phase of the on-going study. A classified list of potential waste causes and a set of materials were formulated by a detailed literature review, studying real project records in a company and by interviewing with experts in the sector. A multi-phase questionnaire survey has been administrated to more than 30 professionals to learn about their perceptions on waste-prone materials, their sources and factors plugging the way of effective waste management within the prefabrication sector in Turkey.
The questionnaire results indicate that, sealing materials, dry wall boards, heat insulation materials, cables and paints are the five most waste-prone material groups. Also, the main sources of waste generation are identified; which reveals the dynamic nature of material waste causes. After the discussion of questionnaire findings, it would be proposed that considering the different sources of waste generation, impacts on project performance and mitigation strategies, an efficient waste management process model and a support tool should be developed for the Turkish prefabricated building companies in order to monitor and control waste generation.

Keywords: Construction; Material Waste; Prefabrication; Waste Causes.

1. Introduction

Construction industry produces significant amount of waste arising from construction activities in diverse form of debris including inert and organic materials or a mixed combination. The common perception about the material waste in construction is generally focuses on the direct material disposals from construction sites as debris [1], however there is a significant type of waste, known as indirect waste, that should be taken into account when studying the material waste in construction industry. Skoyles [2] categorizes wastes in two principal types, including direct and indirect wastes. According to this classification, direct wastes are the physical loss and unrepairable damages of material which

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incorporates both physical and monetary losses, and generally needs disposal and replacement of wasted material. On the other hand, indirect wastes are generally originating from unnecessary material substitutions, excessive use of material and errors during constructions, which only cause monetary losses without physically damage of material. Construction and Demolition wastes are divided into three categories according to the generation phase by Wu et al. [3]: Construction Wastes (CW), Renovation Waste (RW) and Demolition Waste (DW) which generally composed of inert materials with little damage to the environment (e.g., concrete, bricks, etc.). These inert materials are generally wasted in traditional construction methods by wet trade activities; however, some hazardous material components are also generated which requires properly recycling or disposal processes with more cost and environmental effects. The prefabricated industry produces less inert wastes and more hazardous materials therefore waste reduction at source should be more considered. Various definitions have been proposed for waste in literature, Formoso et al. [4] defines the waste as any inefficiency in the utilization of equipment, materials, labour or capital which leads to the use of quantities larger than necessary amounts. The concept of waste in construction covers a wide range of subjects including operations and resources; however, the focus of this study is on the waste of material. Regardless of the waste type, material wastage has considerable economic, environmental and social impacts as well as negative effects on project time, productivity and efficiency.

Materials are the major components of construction projects and constitute the significant portion of project budget. Yu et al. [5] declare that material involves 50% to 80% of total cost in building projects. When waste occurs, usually new purchases should be done to cover the lack of wasted materials, therefore, any direct and indirect costs associated with material procurement will be reflected as cost overrun in total project budget. Ameh and Daniel [6] found that the material wastage contributes about 21% to 30% of cost overruns in construction projects.

In addition to the cost effect of material waste, the environmental impacts of wastes are also considerable. It is obvious that the construction industry, due to its nature, is environmentally unfriendly [5],[7] meaning that the majority of construction and side activities, from material extraction and production to handling and execution, have inherently environmental impacts, which can be escalated with inefficient management of waste. The construction industry consumes energy the nonrenewable natural resources, directly or in production of the construction materials. Udayangani et al. [8] claim that 40% of raw stone, gravel and sand as well as 25% of virgin wood are consumed in construction industry every year in the world. Therefore, the waste of material leads to depleting theses resources during a medium or long-term period and converts them to the construction debris which in turn results in soil and water contamination. These contaminations effects the social health and destroys the public image of the industry [7]. Nowadays, environmental impacts of material waste, due to the wide range of its side effects, are significantly emphasized by researchers in compare with other negative results. Waste usually cause activity delays due to the unplanned waiting time for material repurchasing. Several studies demonstrate the material waste as the major source of schedule delays and low productivity in construction projects [9],[10],[11].

In order to minimize the above-mentioned impacts of material waste and increase the cost, time and environmental performances of projects, it is essential to manage the waste properly during the project life cycle. Poor waste management will lead to rising amount of waste and direct disposal to landfills therefore, cause to extreme impacts on project performance and environment. According to the "Waste Management Hierarchy", the waste management options are prioritized as avoidance, minimization, recycling, treatment and disposal, the most preferred options with highest priorities are avoidance and minimization of waste generation at source [12]. Waste recycling, treatment or disposals have greater cost and environmental effects; therefore, the waste reduction options including avoidance and minimization are preferred as more environmentally friendly and cost-effective methods. However, since the waste generation at construction is not completely preventable and certain levels of unavoidable waste is generally remains, waste reduction at source and proper recycling of residual wastes are considered as the main objectives of sustainable management of wastes in construction [13].

Since the traditional construction methods produce unacceptable level of waste, therefore, shifting the conventional methods to industrial and prefabricated systems is suggested as one of the waste reduction technics at source [14]. Prefabrication reduces the waste generation by minimizing the share of wet-trade and labour intensive activities and increasing the industrial production ratio in compare with traditional methods. Prefabrication also facilitates the implementation of lean production by providing the integrated design and production system which is the main distinction between construction and industry. Prefabrication and industrialization of construction activities, along with the waste minimization in project execution, provides various advantages over conventional construction, including time and cost savings quality and safety improvements. However, the prefabrication itself is associated with significant amount of material waste; which increases the total project cost and time and reduces the final product quality with various environmental impacts. In case of poor waste management in prefabrication, the relative advantages of cost, time and quality will be lost; besides, due to the type of materials used in prefabrication, the recycling and disposal of wasted materials will be more costly and hazardous in compare with traditional construction. Wet-trade construction methods mostly consumes traditional and inert materials; however, the prefabrication generally uses modern construction materials which are mostly the product of complex chemical refinement processes on raw materials. These types of materials although has valuable properties, however, they contain chemical admixtures to provide their enhanced performance and service life; therefore, the recycling or disposal process of these kinds of materials will be more expensive and environmentally hazardous.

Considering the time, cost, quality and environmental advantages of prefabrication above traditional construction, and regarding to the remarkable impact of waste on whole advantage factors, it is obvious that if the waste in prefabrication would not be managed properly, it will not be preferred in construction projects. Therefore, the impacts of poor waste management in prefabrication will be more detrimental than traditional construction and excessive endeavor shall be made to improve the waste management performance in prefabricated construction projects.

In this paper, we will report preliminary findings of an on-going study on management of waste in prefabricated steel structure building projects and point out the need for a systematic waste management process as well as a tool in the prefabricated construction sector.

2. Background and research motivation

During the late decades, in parallel with rapid economic developments in the world, the waste has been arisen as the main problem of the construction industry, and due to the critical role of waste management in sustainable development and lean construction, it becomes as an attractive research topic in recent years. Building sector in all countries incorporates a considerable amount of material waste generation; in the US, approximately 136 million tons of building-related wastes are generated annually [15]; this amount is reported around 70 million tons in UK [16] and about 14 million tons in The Netherlands accounting for about 26% of all waste generation in the country. It also found that construction wastes contribute for around 40% of municipal solid wastes in China [17], 20% - 30% in Australia and 20% in the US [18]. Consequently, the majority of current studies covers the material wastage in building construction projects mostly executed using traditional materials and methods which produces unacceptable level of waste. Since the type of materials used in the conventional construction as well as the construction practices are mostly different than those utilizing in prefabricated methods, therefore generalizing the findings of these studies in prefabrication would not be fully applicable.

On the other hand, the geographic distribution of existing studies are generally concentrated on developed countries rather than in developing economies like Turkey; indicating the importance degree of waste management in developed economies [19]. Since the waste generation in each country is significantly affected by regional practices, materials, regulations and other local specific factors, the existing studies cannot completely reflect the state of waste management in other regions, therefore a huge gap is existing for the waste management studies in regional scales essentially in developing countries like Turkey. Although the construction sector in Turkey constitutes a significant share of national economy and Turkish contractors are among the main corporations of global construction industry, however, there are few studies dealing with construction waste management in Turkey. Considering the prefabrication industry as one of the main ways of industrialization of construction with lower time, cost and waste generation and regarding to the growing need of Turkish contractors to implementation of lean construction concept for achieving strategic advantages in global markets, the prefabrication industry is trending in recent years.

It is generally accepted that the basic advantages of prefabrication can be adversely affected by poor waste management; therefore, the need for efficient waste management is more critical in prefabrication industry in order to achieve the planned performances under lean construction concept. Investigating the sources of waste generation including the identification of wasteful materials and the waste causes are regarded as the prerequisite step for successful implementation of waste reduction in prefabricated construction industry. Besides, improving the waste management performance in Turkish construction industry by investigating the current state of waste management in prefabricated industry as a growing sector not only benefits the national development but also increases the competitiveness of Turkish contractors in global markets. The existing prefabricated building industry in Turkey is generally include concrete and steel structure buildings the focus of this study is prefabricated steel structure building projects.

 DOI 10.3311/CCC2018-103

3. Literature review

Limited studies are available on material waste management in construction industry. Most of the available studies have been focused on waste quantification, source investigation and recycling, mainly in traditional construction and few studies have been done on waste reduction.

Skoyles [2] carried out the first extensive study on material wastage in UK building industry by direct on-site observations and investigating of project records of 114 building projects from 1960 to 1970. They examined the waste generation rate for 37 different materials and reported that the percentage of material wastage in weight ranged from 2% to 15% according to the estimated amount of materials in design stage. The study revealed that the actual material losses are mostly higher than initial estimations; also, the waste rates for each material are extremely variable in different construction sites indicating that most of the existing wastes are avoidable. They also concluded that the major material wastes arise from poor material management on site, incorrect material unloading, poor ground conditions, inadequate transportation equipment and unsuitable packaging. They either reported that the wastes are generally the result of occurrence of multiple causes, rather than single events. In order to reduce the environmental impacts of construction wastes and restrict the rising demand for limited disposal areas in Hong Kong, a study was conducted by The Hong Kong Polytechnic and Hong Kong Construction Association [20] investigating the ways of waste reduction at source. The construction processes with high potential to waste generation in 32 construction sites were monitored during June 1992 to February 1993 and discussed the relative importance of the waste of six different materials including: premixed concrete, steel reinforcement, mortar, bricks and blocks, ceramic tiles, and wood. They also declared that the average waste of premixed concrete in 14 sites were 11% varying from 2.4% to 26.5%.

A research was conducted by Bossink and Brouwers [18] in The Netherlands and investigated the waste of seven materials in five housing projects between April 1993 and June 1994; and reported that direct wastes were ranged from 1% to 10% in the weight of purchased material. Gavilan and Bernold [21] reported the results of an empirical study in US on analyzing three processes including masonry foundations, timber frames and sheetrock drywall in five homes at four construction sites. Residual scraps of bricks, blocks, lumber and sheetrock panels remaining from cutting, non-reusable consumables of wood and packaging and improper handling were identified as the major sources of waste. Pinto [22] carried out a single case study on direct and indirect waste of materials on a residential building project in Brazil using the project records; and found that the percentage of wasted materials varies from 1% to 102% in weight, based on the estimated amounts in design stage. The results also revealed the importance of indirect wastes in compare with direct wastes, for instance the indirect waste of mortar were found as much as 85% of the designed quantities. In Brazil, a detailed study were conducted by Formos et al. [1] in two time phases to explore the main causes of material wastage as well as to investigate the guidelines for waste prevention. The first study monitored 7 materials in 5 projects during 1992-1993 and the second study investigated 18 materials in 69 construction sites during 1996-1998. Some values for the waste rate of investigated materials were found, and the main causes of waste generation in the sector were discussed. The results indicated that the waste of materials in the Brazilian building industry was fairly high and varies significantly across different projects.

From the literature review, it is observed that the current data on material waste in the building industry is relatively scarce and comparing the results of these studies is difficult due to the locational and technical differences between studies, which strongly affects the outcomes. However, it is clearly notable that the level of waste generation in traditional construction methods are significantly high and variable meaning that the waste in most cases is avoidable. Several studies suggest taking actions to reduce the waste generations at source by improving the processes rather than dealing with generated wastes by recycling or reuse. Some studies [23] [24] report that concern about the extra cost of recycling and the quality of recycled materials are key barriers to the promotion of recycling practices in construction. Modular design and prefabricated construction is proposed as one of the effective and feasible methods for process improvement and waste reduction at source. Baldwin et al. [25] confirm that off-site prefabrication of building elements can effectively reduce the waste generation on site. Lachimpad et al. [26] compared the waste generation by three different construction methods in high-rise buildings in Malaysia and found that Industrialized Building Systems are most waste efficient method with a waste generation rate of 0.016 tons/m^2. Wang et al. [27] investigated the factors affecting construction waste minimization at design stage and suggested to develop modular design and prefabrication of building components as one of the more effective ways in waste minimization. Vivian et al. [28] also compared the average waste level of materials in two groups of projects, adopting conventional construction and prefabrication, and found that the wastage level in several trades including: concreting, rebar fixing, bricklaying, tiling and plastering have been reduced, however new wastes have been occurred due to the utilization of new kind of materials in prefabrication (e.g. drywall). A study by Tam et al. [29] suggested that construction waste generation can be fully avoided by using prefabrication technologies. Although the prefabrication promotes the project performance in time, cost, quality and safety however, waste production may not be completely avoided if the material wastage would not be managed properly. This concern is revealed by Jaillon et al. [30] reporting that prefabrication can only provide about 52% reduction in average waste rates.

As a result, to prevent the waste generation in prefabrication, there is a need to identify the sources of existing wastes. There are several studies in different countries to identify the sources of wastes in construction but the focal point of these studies are traditional constructions. Bossink and Brouwers [18] investigated the sources of construction waste in The Netherlands by categorizing 31 sources of waste under 6 main categories including: design, procurement, materials handling, operation, residual and other non-categorized factors. They identified that the main causes of material wastage are related to design, material supply, poor handing in transportation and storage. Adewuyi and Odesola [31] assessed the level of contribution of several factors to construction material waste generation in Nigeria. They identified 74 waste causes and grouped them under 8 main categories including: design and documentation, materials procurement, materials management on site, materials handling, storage and transportation, on-site operations, environmental conditions, site management and practices, and site supervision. The results revealed that reworks due to non-conformance to specifications, waste from cutting uneconomical shapes, and design changes and revisions were the first three highest contributors to material waste. Umar et al.[32] identified 40 causes of waste in Malaysian residential projects and grouped them into seven categories including: site operation, on-site management and planning, material storage and handling, design and documentation, transportation, procurement and external factors and revealed that on-site operation activities rank as the most important sources of waste. Gavilan and Bernold [21] considered 12 factors as main causes of construction waste generation. The study pioneered the grouping of such factors into various categories. Ekanayake and Ofori [33] examined and discussed 27 factors as causes of construction waste. Poon et al. [14] conducted a research in Hong Kong and identified 13 factors that cause material waste in construction. Garas et al. [34] also considered 10 important factors in the generation of construction waste in Egyptian construction industry.

Limited studies exist on construction waste management in Turkey; Polat and Ballard [35] assessed 14 factors in their study to identify the main causes of material waste in Turkish construction industry. Esin and Cosgun [36] conducted a survey among 180 homeowners from different parts in Istanbul to investigate the construction material waste generation due to modifications on residential buildings and proposed to use standard and modular structures for building materials to be easily dismantled without damaging. They also find that one of the sources of frequent modifications is the poor material and labor quality.

4. Research objectives and methodology

On-site processes and the basic materials used in prefabricated building projects are mostly different than those in traditional constructions, which have been investigated in previous studies. Therefore, this study aims to identify the most waste-prone materials and investigate the high priority waste causes in prefabricated building projects.

A mixed research method incorporating qualitative and quantitative approaches were adopted in this research. The methodology includes investigating project records, literature review, interview with professionals, and questionnaire surveying. The initial data from project records and literature review is comprising the basis of interviews; then, all the information collected from interviewing and other resources organized and arranged properly in the form of questionnaires; finally, the data gathered from questionnaire surveying is being analyzed. Since the objective of the research complies with the questionnaire sample surveying method, therefore, this method was used as quantitative analyzing approach in the study.

4.1. Preparation of a list of waste-prone materials

A list of basic material groups was prepared using the data collected from 4 prefabricated steel structure building projects, undertaken by Turkish companies within Turkey and 2 other countries. The bill of quantities and material purchase lists were investigated and a primary list of 47 material groups was prepared considering the relative cost of each group to total material cost, and also with regarding to the material potential for being wasted. The identified materials were classified under 3 different categories including: building materials, mechanical materials and electrical materials. The number of material groups was reduced to 42 by excluding 5 sets from the initial list, considering the minor waste potential or minor cost effect in projects, after interviewing with 9 professionals from prefabricated

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construction industry. As it is shown in Table 1, Table 2, and Table 3 the final material list includes 27 building materials, 9 mechanical materials and 6 electrical materials.

Table 1. Building material groups

Ranking	Building material group	∑w	RII
1	Sealing materials (silicon, etc.)	132	0,78
2	Gypsum board	116	0,68
3	Fiber cement board	104	0,61
4	Heat insulation (rockwool - XPS - glass wool)	102	0,60
5	Paint	98	0,58
6	Fasteners/ connection elements	96	0,56
7	Plaster (gypsum & others)	96	0,56
8	Ceramic tile	96	0,56
9	Un-structural concrete (screed & others)	94	0,55
10	Door handles and accessories	92	0,54
11	Waterproofing material	92	0,54
12	PVC flooring	88	0,52
13	Window handles and accessories	88	0,52
14	Wood (OSB - timber & plywood)	84	0,49
15	Premixed structural concrete	84	0,49
16	Carpet flooring	84	0,49
17	Sandwich panels	80	0,47
18	Cast/cut stone	78	0,46
19	Steel reinforcement	78	0,46
20	Laminated parquets	78	0,46
21	Aluminum board/tiles	76	0,45
22	Vapor barrier	74	0,44
23	Wooden doors	74	0,44
24	Steel profiles/ structural elements	66	0,39
25	Laminated separation panels	64	0,38
26	PVC window	56	0,33
27	Aluminum window	52	0,31

Table 2. Electrical material group

Ranking	Electrical material group	∑w	RII
1	Cables (LV - LC - MV)	102	0,60
2	PVC cable conduits & pipes	98	0,58
3	Cable trays	88	0,52
4	Switch, sockets and electrical installations	86	0,51
5	Electrical equipments	78	0,46
6	Lighting units	74	0,44

Table 3. Mechanical material group

Ranking	Mechanical material group	∑w	RII
1	PVC pipes and fittings	98	0,58
2	Pipe heat insulations	96	0,56
3	PPRC pipes and fittings	90	0,53
4	Sanitary/ bathroom accessories	84	0,49
5	HDPE pipes and fittings	82	0,48
6	Air ducts and fittings	82	0,48
7	Sanitary wares	82	0,48
8	Steel pipes and fittings	78	0,46
9	Mechanical equipments	58	0,34

4.2. Identifying waste causes

A categorized list of potential waste causes, including 49 items were identified through a detailed literature review and classified under 5 categories. The prepared list was discussed by 9 sector professionals and some specific waste causes that were not identified in literature were added and some causes with same concepts were merged together; ultimately the final list with 46 waste causes and 6 different categories was prepared as shown in Table 4.

4.3. Questionnaire design

Arranging the final results of interviews, and considering the length of the surveys, a two-phase questionnaire was designed and distributed between sector professionals to learn about their perceptions about wasteful materials and waste causes. The first phase of survey was designed to elicit the perception of respondents about the most waste-prone materials for three disciplines including: building, electrical, and mechanical works; and the second phase were seeking the answers for most critical waste causes. The questionnaires consisted of two sections, the first section was related to the general information of respondents and their company profile; like, company size and their experience in prefabricated construction industry. In second section, the respondents were required to identify their perceptions about most waste-prone materials and waste causes in first and second phases respectively. The first phase of the survey asks the respondents to evaluate the 42 identified materials (Table 1, Table 2, Table 3) according to their level of waste-proneness using a five-point Likert system ranged from 1 to 5; representing: 1 = very low; 2 = low; 3 = average; 4 = high; and 5 = very high. After the results of the first phase were analyzed and the most wasteful materials were identified for each discipline; the respondents required to evaluate the waste causes in general and for most wasteful material groups in each discipline. The survey in second phase were asking the respondents to rank the degree of contribution of 46 identified waste causes (Table 4) in waste generation based on their experience in prefabricated steel structure projects according to the given five-point Likert scale representing 1 = very little; 2 = little; 3 = moderate; 4 = great; and 5 = extreme.

4.4. Sampling and data collection

A representative sample is a small set of a larger group that adequately reflects the characteristics of its population as a whole. Statistical methods are generally used for designing the representative sample in questionnaire surveying, to enable the generalization of findings to the entire population [37]. For this purpose, 11 Turkish companies with national and international experiences in steel structure prefabricated building projects were identified using information obtained from Turkish Contractors Association (TMB). 73 questionnaires were sent by Email to professionals from these companies which were specified using business network connections and professional social networks such as Linkedin. 34 responses for first phase and 45 replies for second phase were collected from 5 participant companies.

Table 4. Categorized material waste causes

Waste category	Waste cause
Design	Poor design and details
	Poor estimations
	Poor specifications
	Changes in designs and specifications
	Complexity and low constructability of design
	Poor interdisciplinary design integration
	Improper/ wrong material selection or substitution
	Ignorance of material specifications in designs
Procurement	Ordering errors (quality/quantity errors, wrong selection/substitution)
	Supplying errors by suppliers (quality/quantity errors)
	Early or late delivery
	Defective/rejected products
	Ordering limitations applied by suppliers (quantity/quality limitations)
Transportation	Poor loading and unloading
	Inappropriate packing for transportation
	Multiple shipment/ transportation points
	Accident during transportation
	Poor site accessibility/ road condition
Storage and distribution	Poor/improper handling and distribution on site
	Poor/improper storage and protection
	Unpacked/ improper packaging of materials
	Multiple/ unnecessary relocating or Handling
	Excessive/ unnecessary inventories
	Poor site storage capacity
	Accidents during storage and distribution
	Handling equipment failure (breakdown or malfunctioning)
	Untraceable/ left-over materials on site
	Poor stock management
Construction	Using poor quality/ wrong material
	Poor/ wrong execution of work
	Damages by subsequent trades
	Excessive/ unoptimized cutting (conversion waste)
	Accidents during construction
	Excessive use of material
	Overproduction
	Ignorance of designs/ method statements during construction
	Unavoidable process waste
External waste affecting factors	Poor planning and scheduling
	Poor waste management
	Poor supervision and control
	Poor project contracting/ subcontracting
	Unfavorable weather conditions
	Natural/ manmade disasters (e.g. earthquake, floods, war, etc.)
	Unknown site conditions
	Theft and vandalism
	Unskilled/ unexperienced labour

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The majority of companies (60%) are large companies with more than 250 employees; and the remaining (40%) are medium size companies with employees between 50 to 250 people. 80% of companies have more than 20 years of experience in national and international prefabricated building projects which demonstrates their understanding of the construction waste in Turkey and other countries. Moreover, 67% of participants have more than 10 years of experience in prefabrication which means that they are professionals with significant knowledge about material wastes and sources of waste generation in construction sites. Regarding to the profile of targeted companies and respondents, it is obvious that the representative sample has a uniform and homogenous composition; also, it is expected that the responses will be adequately consistent; therefore, as it is declared by De Vaus [37], the relatively small sample size can suffice in a homogeneous population in which most people will answer a question similarly. Besides, the more uniform and consistent a population is, the smaller a sample that can be drawn from it for a research purpose will be [38]. Considering the level of participation from 45% of targeted companies (46.6% in phase 1; 61.6% in phase 2) and the uniformity of the respondents and expected consistent answers from participants, this level of participation for sample study would be sufficient.

5. Data analysis

To determine the relative ranking of the most waste-prone materials and waste causes, the responses collected from surveys were evaluated according to the Relative Importance Index (RII) using the following equation:

$$RII = \frac{\sum W}{A \times N} \qquad (0 \leq RII \leq 1) \tag{1}$$

Where:

W: The weight given to each factor by the respondents and ranges from 1 to 5,
A: The highest weight and,
N: The total number of respondents

The Relative Importance Index (RII) was calculated for each material type and for each cause; the materials and causes were ranked according to the value of RII. The results of material ranking based on RII, are demonstrated for building, electrical and mechanical materials in Table 1, Table 2, and Table 3 respectively. According to the results, sealing materials, wall and ceiling boards (gypsum and fiber cement boards), heat insulation materials, and paint, are the most five waste-prone building materials in prefabricated steel structure projects. In addition , cables in electrical material group and PVC pipes and fittings in mechanical material group has the greatest RII and are evaluated as the most wasteful materials by respondents.

Based on the results of first phase of survey, one material from each discipline including “wall and ceiling boards”, “pipes and fittings”, and “cables” were selected considering their RII value and cost and quantity in prefabricated projects, to investigate the related waste sources in second phase of survey.

The respondents in second phase, were asked to evaluate the waste causes in general and for selected three materials either. According to the results, demonstrated in Table 5 and Table 6, “poor site storage capacity” and “poor stock management” are the most critical waste causes in general evaluation. On the other hand, “multiple/ unnecessary relocating or handling” of material is identified as the highest rated waste cause for “wall and ceiling boards” whereas, “unpacked/ improper packaging of materials” and “Damages by subsequent trades” has the highest importance in waste generation of “pipes and fittings” and “cables” respectively.

 DOI 10.3311/CCC2018-103

Table 5. General evaluation of material waste causes

Ranking	Waste causes	∑w	RII
1	Poor site storage capacity	184	0,82
2	Poor stock management	175	0,78
3	Poor/ improper storage and protection	168	0,75
4	Unskilled/ unexperienced labour	157	0,70
5	Poor estimations	155	0,69
6	Poor design and details	153	0,68
7	Unpacked/ improper packaging of materials	153	0,68
8	Multiple/ unnecessary relocating at site	152	0,68
9	Unfavorable weather conditions	151	0,67
10	Changes in designs and specifications	151	0,67

Table 6. Five most important waste causes for different materials

Ranking	Waste causes	RII
Wall and ceiling boards		
1	Multiple/ unnecessary relocating or Handling	0,73
2	Poor/ improper storage and protection	0,71
3	Poor site storage capacity	0,71
4	Excessive/ unoptimized cutting (conversion waste)	0,70
5	Unskilled/ unexperienced labour	0,69
Pipes and fittings		
1	Unpacked/ improper packaging of materials	0,89
2	Untraceable/ left-over materials on site	0,87
3	Poor interdisciplinary design integration	0,82
4	Ignorance of material specifications in designs	0,82
5	Ordering errors (quality or quantity errors, wrong selection or substitution)	0,78
Cables		
1	Damages by subsequent trades	0,83
2	Ignorance of designs/ method statements during construction	0,83
3	Poor planning and scheduling	0,78
4	Theft and vandalism	0,75
5	Poor/ improper storage and protection	0,70

6. Discussion of findings and conclusions

The construction processes in prefabrication are mostly industrialized, meaning that, depending on the level of prefabrication, the whole or a portion of building elements are fabricated in production plants which are generally apart from construction sites. Therefore, proper packaging, transportation and storage of manufactured elements are significantly important in this sector. The most common prefabricated elements are wall and roof panels, structural elements, suspended ceilings, doors and windows and the major construction activities on site focus on assembly and installation of these elements. Considering this method of construction, the results of the ranking of most waste-prone materials and critical waste causes can be discussed accordingly. The study confirms that sealing materials are the most wasteful material in prefabrication; indicating that water leakage is a common problem of this industry as it is mentioned by Poon et al [14] and Tam et al [39]. Due to the problems that arise from poor integration of non-standardized designs with production and on-site assembly, sealing of assembled elements seems to be one of the most challenging obstacles in prefabrication which leads to excessive use of sealing materials. Gypsum and fiber cement boards are ranked as second and third most waste-prone materials respectively in Table 1. These are the major covering materials in prefabricated wall and roof elements; therefore, as it is mentioned in Table 6, multiple relocating and poor storage and protection at construction sites may lead to increasing damages on them.

Cables are identified as the most waste-prone material in electrical material group, which are affected by damages from other trades, rout changes by ignoring design during construction and theft or damage due to improper storage and protection on site. In mechanical group of materials, PVC pipes and fittings are evaluated as the most waste-prone materials that improper packing, left-over on site and poor interdisciplinary design integration are the most important causes for their waste generation.

The results of the study reveal that, the most waste-prone materials in prefabrication industry are totally different than those in traditional construction. Considering the chemical composition of these materials, it is observed that in contrast to traditional construction with inert combination of wastes, the wasted materials in prefabrication are mostly made from synthetic materials. The recycling cost and environmental effect of improper disposal of these materials are extremely high; therefore, efficient management of material waste in prefabrication is considerably important.

In the light of the findings above, it is obvious that the most 10 important waste causes belong to three waste categories identified in Table 4. Accordingly, 50% of waste causes are originated from “storage and distribution”, 30% from “design” and 20% of waste sources are related to “external affecting factors” such as unskilled labour and weather conditions. Therefore, proper packing of materials for long-distance transportation and appropriate storage and protection against diverse weather conditions on construction sites are the major actions should be taken for waste reduction in prefabrication. Besides, standardization of designs and integration of design, production and on-site assembly works, with exact consideration of site conditions will improve the quality of design and details. Moreover, the amount of revisions after design phase must be reduced to overcome the waste generation, arising from on-site variations, for this purpose the customer needs and requirements must be exactly identified and incorporated in designs, also the interdisciplinary integration should be improved in designs by using Building Information Modeling (BIM). Application of BIM in design process not only reduces the clashes by improving the accuracy of design and details, but also increases the validity of quantity estimations which is found as one of the substantial waste causes as indicated in Table 5.

The study also confirms that the waste can be originated from different sources for various materials. The results of waste causes ranking in general and specifically for three different materials shown in Table 5 and Table 6, indicates the variability and flexibility of waste causes in each case. Therefore, since the waste is not completely avoidable and whole sources of waste cannot be managed properly, it would be more efficient to focus on the most waste-prone materials and significant waste causes to achieve more effective waste management results. Also, the project management team must be able to deal with the waste sources prior to their occurrence, or at the earliest time they are recognized during project life cycle. For this purpose, the research team is developing a tool for facilitating the tracking of the waste generation by controlling the related waste sources and recording the data while the project is going on. This will provide a corporate knowledge from previous projects for efficient prediction of possible waste generation sources prior to project commence and facilitates an effective waste prediction and management during project execution. Since late preventive actions would be more costly, or in some cases impossible, this tool is expected to be useful for timely management of waste in prefabricated construction projects; and will lead to increase in the efficiency of projects by enhancing the time, cost and environmental performances.

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Application of heart rate variability for thermal comfort in office buildings in real-life conditions

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Abstract

In the context of building energy efficiency, occupants' preferences can be considered as a source of information complementary to those in traditional building management systems (BMS). The general availability of wearable devices in recent years has increased interest in this ecosystem of technologies, as well as in their practical applications and those that can potentially derive from them. This study aims at investigating the applicability of wearable heart rate sensors for evaluating aspects of mood associated to stress/comfort, and in particular in relation to thermal comfort. A procedure for data gathering and analysis is proposed and tested in an office building in real-life conditions. First results show that no clear pattern of comfort vs. discomfort can be observed in data during testing. In addition, some of the challenges of applicability of the technique in real-life conditions are discussed in the study.

Keywords: Building management systems; energy efficiency; wearable device; heart rate variability; occupant comfort.

1. Introduction

Thermal comfort is an important criterion in design, operation and commissioning of commercial and residential buildings. Thermal comfort is stated as a key factor that affects not only comfort but also health and wellbeing, which hints at broader feelings or perceptions of satisfaction and happiness. However, building systems might not operate fully adequately due to increasing demand on maintaining occupant comfort. Today, most buildings and system components are designed based on the standards, which define the range of thermal environmental conditions acceptable to a majority of users. Given the fact that these systems operate according to code defined occupant comfort ranges, they might not necessarily reflect the real comfort levels of occupants. Recent studies show that thermal comfort standards, such as ASHRAE 55 [1] and ISO 7730 [2], underestimate the percentage of dissatisfied users in indoor environments [3, 4, 5]. Subsequently, occupants interact with building systems to ensure that their comfort levels are met. Therefore, occupants' satisfaction and preferences need to be considered as a complementary source of information in the operation of buildings.

To determine satisfaction, and thus, comfort levels of occupants, surveys are widely used to provide feedback with respect to thermal perceptions. However, low participation to the surveys might cause misleading results, and thus, wrong strategies to maintain comfort in buildings. Recently wearable devices have emerged as an alternative source for obtaining user comfort and state through monitoring Heart Rate Variability (HRV). HRV is the variability in heartbeat intervals, which corresponds to the time between successive heartbeats. HRV has been studied as a potential indicator of various clinical conditions [6] and user states as well as comfort, such as stress [7], mental strain [8], bipolar disorder [9], and others. Wearable devices have directly brought a large interest around the

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potential applications of monitoring physiological parameters in a convenient and personalized way in sectors such as sports and health, among others.

This study provides an initial feasibility assessment for the applicability of wearable heart rate sensors for evaluating aspects of mood associated to stress/comfort, and in particular in relation to thermal comfort in buildings. An office building in Eibar, Spain was selected as a test bed and field studies were carried out to investigate the applicability of wearable sensors, and thus, HRV for obtaining user comfort in indoor environments. The following sections of the paper present the literature review, describe the case study, analyze the initial results and finally provide discussions and conclusion.

2. Literature review

Wearable devices have emerged as an alternative source for exploring user comfort and state through monitoring Heart Rate Variability (HRV). Recently, wearable devices are evolving very fast and some big companies are pushing great efforts on improving them. These devices incorporate new sensors for monitoring the health of the users and new methods for integration of the data provided in third parties' applications by means of standards in communication protocols like Bluetooth Low Energy or supplying aggregated data by means of a public API. Along with this interest, a renewed one has originated about the study of psychological human aspects using wearable devices, in particular from physiological indicators of arousal, stress, fatigue, etc., which can be linked to the field of affective computing. Concisely, affective computing studies the identification of emotions and mood and, thus, comfort of users by systems and devices [10].

Practical applications of the evaluation of psycho-physiological human aspects by systems and devices require various technologies. Wearable devices are attached to human body and are typically based on novel small sensor devices with efficient communication and energy consumption capabilities, for instance embedded in smart textiles, strap bands or wristbands. Many wearable devices connect to a gateway forming what is known as a body area network (BAN). The gateway is in many cases a smartphone, which also provides software application and interfacing capabilities. Often, the smartphone communicates with remote systems as well. These remote systems or cloud may provide long-term data, aggregated data, additional analysis and reporting, and potentially provide access to authorized parties, such as for example trainers or medical doctors advising the user. Software algorithms for data processing and interpretation are also one of the key technologies needed, see for example [11] for a review. In particular, physiological correlations of emotions and mood rely on models for their interpretation.

HRV is the variability in heartbeat intervals, which corresponds to the time between successive heartbeats. Heartbeat interval is called RR interval as well, since so called R peaks in an electrocardiogram (ECG) waveform are used as a signal of the occurrence of a heartbeat. Extraction of RR intervals from ECG may require substantial processing, especially due to the fact that some measurements are spurious (ectopic beats) or noisy. Normal beats are extracted and the intervals measured are called NN intervals. HRV measurements are derived from NN intervals. Extraction of RR intervals from photoplethysmography (PPG) waveforms obtained by optical sensors is a more recent research topic [12]. A joint European and North American Task Force published a paper with guidelines for measuring, interpreting and clinical use of HRV [13]. The paper includes a classification and recommendations on various measurements of HRV from NN intervals.

Various time domain methods such as statistical and geometric methods are described along with frequency domain methods. Some are simple calculations, such as the mean NN interval (MEANNN) whereas others use statistical methods, involving calculations of variance, differences or proportions, such as the standard deviation of NN intervals (SDNN) or the square root of the mean squared differences of successive NN intervals (RMSSD). The third type of time domain method converts the series of NN intervals in geometric patterns and characterizes their properties. For instance, the HRV triangular index characterizes the density distribution of NN intervals by means of dividing the integral of the distribution by its maximum value.

Frequency domain methods distinguish between extracting short-term spectral components (typically five minute interval recordings) and long-term spectral analysis (twenty-four hours periods). The ratio between low frequency (LF) and high frequency (HF) components (LF/HF) are among the short-term components, whereas a long-term indicator is the slope of the spectrum obtained from a twenty-four hours interval. It should be noted that there are several existing tools for HRV analysis that implement HRV indicators, such as for instance Kubios (www.kubios.com) and HRVAS [14], among others.

HRV is related to the regulation of cardiac functions, and is responsive to modulations in sympathetic and parasympathetic nervous system. Due to this characteristic, HRV has been studied not only as a clinical tool [15] but also as a potential variable, which is sensitive to various situations, such as stress [6] or thermoregulation. As an example, Flouris et al. [16] studied HRV data in cold-induced vasodilatation experiments through water immersions at 42ºC and 12ºC water temperature. Liu et al. [17] studied HRV using LF/HF ratio for air temperatures between 21ºC and 30ºC in a climate chamber under controlled conditions. The results show that LF/HF values are higher at discomfort level compared to comfort level. Some researchers studied HRV along with other measurements. Yao et al. [18] measured HRV, skin temperature and electroencephalography (EEG). Four ambient temperatures ranging between 21ºC to 29ºC were tested in a climate chamber. The authors concluded that there is a qualitative relationship between thermal comfort and the measurements. Xiong et al. [19] measured biochemical markers (interleukin-6 and heat stress protein 70), oral temperature, skin temperature, blood oxygen saturation, respiration rate, heart rate and heart rate variability. The experiment was carried out in a climate chamber containing two rooms connected by a door. Each room was kept at a different temperature, ranging from 5ºC to 15ºC, so that there was a temperature step when moving from one room to the other. The results show that interleukin-6, oral and skin temperature, HR and HRV could be potential indicators for the effects of temperature steps. Furthermore, a relationship between subjective perceptions and physiological measurements was observed based on the correlation analysis.

Besides personal comfort, benefits of this research on subjects' thermal comfort may be linked to novel devices [20], the development of alternative HVAC/building designs and even productivity [21]. However, existing studies in this domain are mainly conducted in climate chambers and, thus, there is a need to explore the applicability of HRV in real life conditions.

3. Materials

3.1. Test bed description

An office building, which is located in Eibar, Spain, is selected as the case study. Under the Köppen climate classification, Eibar is included in C zone and Cfb type, which is known as temperate oceanic climate with mild temperatures and warm summers. The tests were conducted in a large open space area (Figure 1), which is a shared office with desks. The room has 2043 m^2 floor area with 200 to 250 occupants daily. Heating and cooling is central and there is mechanical ventilation. The front wall of the area is covered with panels of glass from the floor to the ceiling. The roof stands out of the building floor, and thus, mitigates the effects of direct sunlight especially in the afternoon.

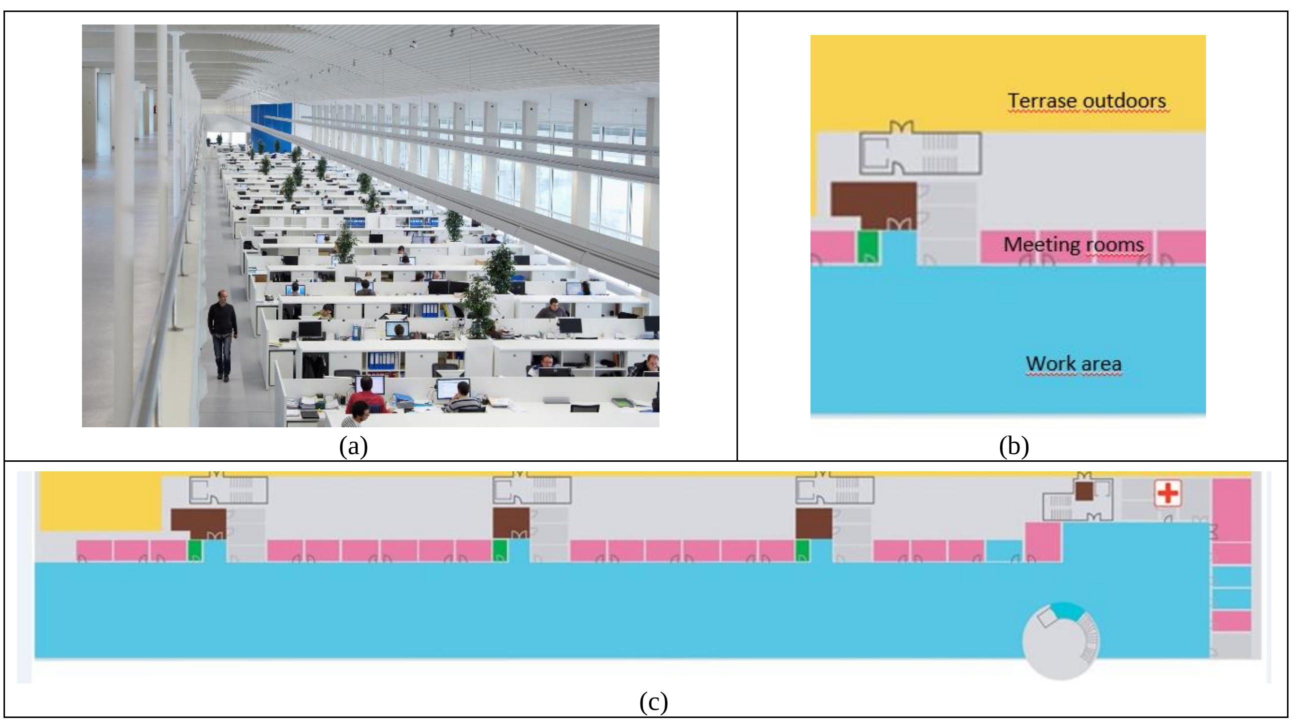

Fig. 1. Test bed setting: (a) image (b) floor plan of mid-section (c) floor plan

3.2. Methodology

The procedure devised regarding data processing and analysis is depicted in Figure 2. An ECG sensor on a chest strap is used to gather occupants' heart rate data, in particular the RR interval. Then, an analysis of the RR interval is performed and various HRV indicators are extracted. Next, data was aggregated and analyzed in terms of differences with respect to the previous day.

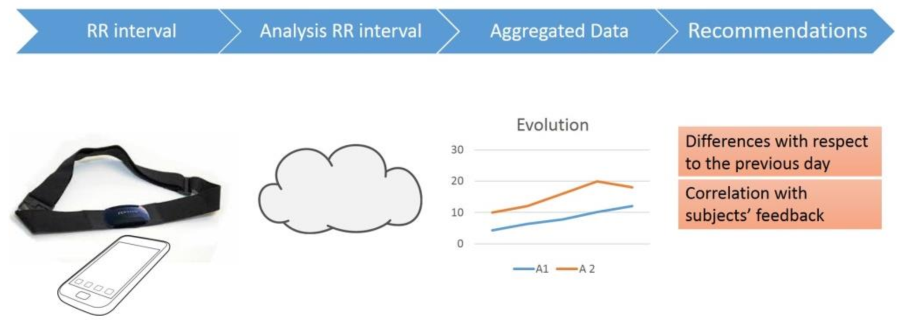

Fig 2. Procedure flow for utilizing HRV in real-life situations

In particular, data is gathered by the wearable device provided with an electrical sensor to record the electrical activity of the heart. The device has a software to obtain the signal of the specific values of Heart Rate and RR interval. Then, the data is published by the wearable device under the standard protocol "Bluetooth Low Energy" (BLE), using the Generic Attributes Profile – GATT [22] and more specifically by the profile related to the Heart Rate version 1.0 [23]. This means that any application that supports the "Bluetooth Low Energy" protocol and the Heart Rate Profile is able to get these data for processing as needed. Once the BLE application detects data under the Heart Rate Profile gets the data and publishes it onto a cloud service. The cloud service is in charge of two main tasks, the first one is storing the data received in a storage database and the second one is executing the analysis of the data collected for a specific period of time. Then, the data stored are utilized for further specific analysis and reporting.

In this study, short-term recordings are taken into account for analysis. Regarding HRV indicator computation, a five minutes period is selected according to the Task Force recommendations [13]. Before further calculations, from each period of RR data values those differing more than 20% with respect to the previous RR value in the series are removed. If a minimum number of data values are not preserved for calculation of LF/HF, the period is discarded and the HRV indicators are not calculated from that period [24]. Otherwise, the HRV indicators such as the following are computed:

- The mean of NN interval values (MEANNN).
- The standard deviation of the NN interval values (SDNN).
- The square root of the mean squared differences of successive NN intervals (RMSSD).
- The integral of the distribution of NN interval values divided by its maximum (HRV triangular index).
- The ratio between low and high frequency components of the NN interval series (LF/HF).

For calculating the LF/HF ratio, a cubic spline interpolation of the NN interval series is performed followed by re-sampling. Then, the data series mean is removed and a Hanning window is applied before computing the power spectral density (PSD). From the PSD, the low frequency component (LF) and high frequency component (HF) are calculated by means of integrating the PSD values within their respective limits. Finally, LF/HF ratio is calculated.

3.3. On-site measurements

Heartbeat data gathering can be done by means of several types of devices. To select the proper wearable devices to be used, there are some relevant criteria to be taken into account: accuracy, periodicity of monitoring and user comfort. The measurement accuracy is very important since the quality of measurement directly affects the quality of the signal analysis. The accuracy highly depends on two main factors: the type of sensor, which can be "red infrared light sensor", "optical", "contact sensors" and the part of the body where the sensor must be worn, which can be “chest straps”, “arm”, “finger” [13]. The periodicity of monitoring is very important, because the data analysis requires a minimum set of data in order to guarantee the validity of the analysis conducted. The comfortability of the wearable device is very important for the success of the test, since the more comfortable the device is, the more the user is engaged in wearing the device.

There are several types of health monitors depending on the way of monitoring the signals, which can be either by continuous monitoring or by synchronization monitoring. Continuous monitoring sends multiple measures by second, providing a huge amount of data to be processed allowing a more complete set of data to get more precision in the analysis. Synchronization monitoring sends one measure per second, in the best cases. So, it is required to assess if this set of data is enough for the analysis.

In this study, HRV and RR intervals were measured via the “Zephyr Bioharness HxM Smart”, which is worn on the chest (Figure 2, left image). The device is selected due to its characteristics with respect to accuracy, periodicity of monitoring and quality of the data. The operating limits of the device are -10 to 50 °C and 5 to 95% with respect to indoor temperature and relative humidity, respectively. Data is gathered by the wearable device provided with an electrical sensor to record the electrical activity of the heart. The device includes a software library to obtain the signal of the specific values of Heart Rate and RR interval. In addition, a smartphone powered with Android operative system with an application that supports BLE has been developed for recording the signal and translate into data. The characteristics of the measurement system are presented in Table 1.

Table 1. Specifications of the test equipment.

	Parameter		
	Heart Rate	Transmit	Frequency
Measuring range	25 to 240 BPM	10 m	2.4 to 2.4835 GHz

Two subjects participated in tests from February to September 2017. Morning and afternoon sessions lasting two hours each were scheduled. It should be noted that participants were volunteers and were aware of the purpose and procedure of data collection. The procedure defined for the tests requires the users to carry the wearable devices under normal working conditions, and, thus, no special activity was defined for the tests. Accordingly, participants were conducting their usual office activities during the tests. These activities comprise working on a computer, reading/writing, thinking/analyzing, having meetings with colleagues, etc. It should be noted that occasional movements around the office are also included. In some cases, sporadic episodes were reported or provoked, regarding thermal stress or discomfort (e.g. feeling cold), wearing extra clothing that increases thermal insulation, or sustained proximity to heaters/coolers, as they may be useful for the analysis of deviations from normality. Descriptions of tests and reported sporadic episodes are listed in Table 2.

Table 2. Description of the tests

Test ID	Date	Duration (min.)	Reported sporadic episode
1	February 8th, 2017	120	Feeling cold
2	May 12th, 2017	120	Provoked hot feeling (Wearing extra clothing (thermic/winter shirts and a sweater).
3	September 14th, 2017	60	Portable fan heater used to provoke a hot feeling.

4. Results

A procedure for further data processing is devised in order to aggregate data and oriented towards assessing normality and potentially providing warnings. For data aggregation, influence of the time of the day and intra-/inter-subject variability is considered. Regarding the influence of time of the day, it is known that heart rate activity presents a cyclic daily pattern. Therefore, the approach taken is that data collected is to be aggregated (mean value) and compared to data in the same time-frame of the day (i.e. morning hours). Regarding intra-subject variability, the variation (difference) of the aforementioned aggregated (mean) value at the same time-frame of different days is to be computed for each subject separately. In summary, the proposed methodology is to compute the differences of aggregated HRV values between different time periods for each subject separately, and to obtain an aggregate of the

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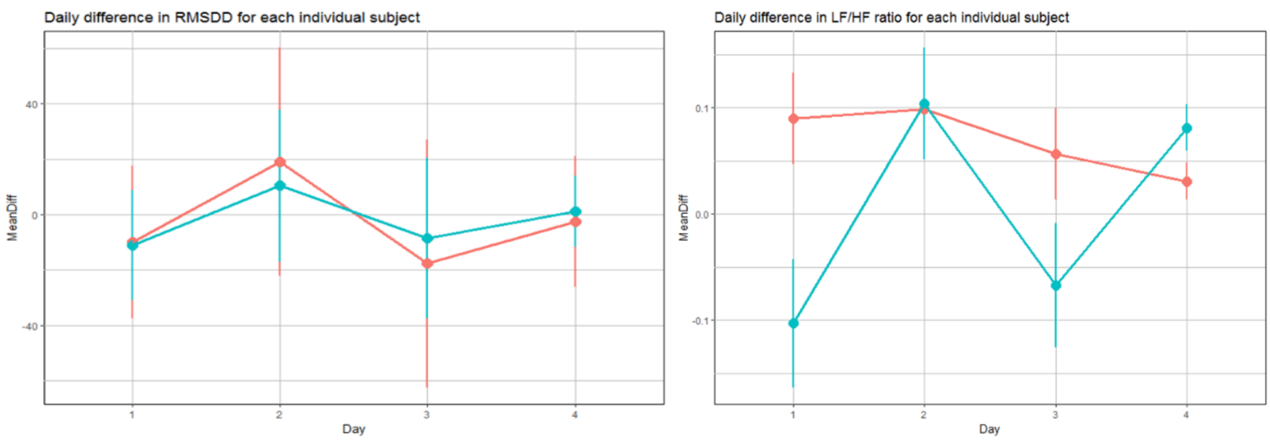
overall trend for a building or room via the observed individual trends. When the trend departs from the average in the short-term (i.e. tentatively, two standard deviations from the data in the previous five days), a warning is issued.

Daily differences of two different subjects within four days in a week are illustrated in Figure 3. Data was gathered during morning hours. As can be seen, mean values are relatively steady, in spite of an important dispersion in point measures. It should be noted that the time-frame used for data aggregation was 30 minutes, in spite of potentially increasing daily variability in average values with respect to that showed in Figure 3, in order to assess any daily differences and warnings that may occur at the time of reported episodes and tests.



(a) (b)

Figure 3. (a) Daily difference in RMSDD (b) LF/HF ratio

Since no clear differences or patterns were observed on aggregated data, the series of actual values of HRV indicators calculated every five minutes was analysed with respect to a number of relevant episodes and tests reported, looking for trends and changes in the value of the HRV indicators during those situations with respect to values in normal situations. However, no clear pattern of comfort vs. discomfort was observed in the data either for the episodes or tests reported. In particular, LF/HF ratio showed a constant trend before, during and after all episodes, including sporadic ones with hot or cold feeling (other HRV parameters showed a pattern similar to normal state sessions, which means that no sporadic episodes were reported).

Values for the HRV indicators in the sporadic episodes listed in Table 2, and also in a week with no reported or provoked episodes are shown in Table 3. For test IDs 1 and 3 in Table 2, values of the indicators are shown before, during and after the test. A whole session was spent on test ID 2, therefore the values of the indicators are shown for the testing day and for the day before the testing day. In Table 3, within test differences are not pronounced, maybe with the exception of higher standard deviation of SDNN and RMSSD in tests 2 and 3. There is a trend toward lower values in all indicators as the year advances (February (test 1), May (test 2), July (normal state week) and September (test 3)).

Table 3. Values of the HRV indicators

Test ID		MEANNN (ms)	SDNN (ms)	RMSSD (ms)	HRV triangular index	LF/HF
1	Before	1072 ± 316	88 ± 69	53 ± 47	22 ± 11	3.2 ± 0.5
	During	1148 ± 316	95 ± 55	54 ± 38	25 ± 9	3.0 ± 0.5
	After	1155 ± 279	89 ± 39	51 ± 20	23 ± 10	2.9 ± 0.4
2	Day Before	912 ± 30	58 ± 19	46 ± 25	18 ± 5	0.7 ± 0.0
	Testing day	819 ± 30	56 ± 69	43 ± 53	13 ± 3	0.7 ± 0.0
3	Before	797 ± 0	23 ± 8	16 ± 0	10 ± 3	0.9 ± 0.0
	During	754 ± 7	38 ± 18	31 ± 28	11 ± 2	0.9 ± 0.0
	After	823 ± 4	28 ± 2	18 ± 3	10 ± 2	0.9 ± 0.0
Normal state week		843 ± 32	41 ± 15	24 ± 13	14 ± 4	0.8 ± 0.0

5. Discussion and Conclusion

In the context of building energy efficiency, this paper reviews the feasibility and potential of heart rate variability for assessing aspects of user state associated to stress/comfort, and in particular in relation to occupant's thermal comfort. Then, a procedure devised for usage of the technologies in real-life situations is presented and reports on performed tests are provided. The results lead to identify the challenges and potential of applicability of the technique in real-life situations, which are discussed below.

First finding is that a certain amount of variability on physiological data should be expected in real-life situations as compared to experiments performed in a laboratory under well controlled conditions, as found in the literature so far. Factors such as movement and others can cause variability in the data, which can have an effect on the potential to ascertain differences and trends, which then may appear due to changes in comfort level in the conditions studied, and on the potential to build alerts. Acclimatization, circadian rhythms, consumption of food/drinks, localization of climatization systems, individual physiology, age, fitness, sex may have some effect on comfort, and can be an argument in favour of more personalized thermal comfort designs [25]. Also, in favour of more personalized comfort strategies. Both the environment and individual differences represent a challenge in real-life situations. In this study, this challenge is approached by means of data aggregation mechanisms, which aim to normalise for individual differences and by looking at short term data for minimizing the impact in the analysis of potential modifications occurring in the environment and occupants.

Regarding the heart rate variability, some limitations in terms of lack of standard methodology, consensus and reliability have been discussed by researchers [7, 26, 27]. There is a certain overlap in terms of characterization of for example stress and comfort, and it is not yet clear which are accurate parameters. Studies on the use of additional sensors may potentially be beneficial as well in order to complement measurements such as HRV and to contribute to put additional factors in context in real-life situations.

Overall, during the usage of the solution proposed, notable dispersion has been observed in the HRV indicators, especially in time-domain indicators (MEANNN, RMSSD, SDNN, HRV triangular index). For LF/HF ratio, it is plausible that data is stabilized when following the guidelines for testing (mainly following the daily period for testing and doing usual office activities). Therefore, a preliminary stage of data normality has been achieved in some cases. Nonetheless, no clear pattern of comfort vs. discomfort has been observed in data for the episodes or anomalous situations reported. Last, the very limited number of participants in the sample should be augmented to provide more concrete evidence concerning the validity of the measurement system with respect to the variability of the data registered in daily situations. In this sense a new test with a similar methodology but a broader basis (from 15 to 20 participants) is expected to be conducted at two different sites during next months.

Research on HRV and thermal comfort is currently alive in the state-of-the-art literature. A joint position statement by the e-Cardiology ESC Working Group and the European Heart Rhythm Association co-endorsed by the Asia Pacific Heart Rhythm Society presents advances on the HRV indicators [28]. More recently, further studies in practical application [29] and in laboratory experimentation and machine learning-based classification modelling [30] have been published.

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Assessment of green building standards: Identifying aspects/opportunities for future improvements

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Abstract

Social problems and environmental degradation are the result of economic development in many parts of the world. Balancing social, environment and economic is the goal of sustainable development. Many countries have developed environmental assessment standards to support sustainable development concept. This paper presents a comparative study of green building evaluation standards in both developed and developing countries to find similarities and differences in order to make future improvement on each standard to full field sustainable development concept. The comparison is done by reorganize criteria listed in those standards to match BREEAM evaluation criteria for ease of study. The study found that most building evaluation systems focuses mainly on environment and then economic while pay less attention on social side and most criteria gives higher emphasis to energy and environmental mitigation issues with "proactive" measures. For the future development of evaluation standard, social impact need to be improved and minimization of building material use need to be preventive more than reactive management.

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Keywords: Green Building Standards; Architecture; Sustainability;

1. Introduction

Natural resources are fundamental to human survival [1]. The development of economy and society has resulted in an unstoppable and growing consumption of natural resources and the degradation of the environment. Even though the interrelatedness among economic, social and environmental aspect of human developments is key to sustainability, it has been a huge challenge to manage. Focusing on one aspect often leads to miscalculations in other areas and "unsustainable" outcomes, sometimes disastrous [2]. Islam [3] found that long term economic growth might not benefit as much as the cost of environmental deterioration.

Architecture and construction have been a part of sustainability discourse among academics and professionals. Future buildings are being required to achieve higher performance and functionality with minimal environmental impact, while encouraging improvements in economic and social (and cultural) dimensions at local, regional and global levels [4]. The building and construction industry plays a critical role in a nation's economic and social development and is heavily responsible for the negative impact on the environment because of their large material and energy consumption, as well as their pollutant emissions throughout buildings' life cycle. Sustainable or green building [5] is "the practice of creating structures and implementing processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction". In respond to the need, many countries have developed tools to evaluate building's performance with respect to sustainable or green building concept. The Building Research Environmental

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Assessment Method (BREEAM) was the first environmental certification system created in 1990 in the Great Britain. Many countries have since followed suit with their versions of evaluation standards based on BREEAM. Each standard encourages green building through a suite of sustainability strategies that promote energy and resource efficiency, water conservation, indoor air quality and more. These green building assessment standards share many similarities in their evaluation criteria; they all include aspects such as management, water, energy efficiency, materials, waste management, site selection, pollution and indoor environment quality. The purposes of comparing 9 green building evaluation standards (for Non Residential and New Construction) are (1) to highlight the main emphases in each evaluation standard; and (2) to evaluate the distribution of criteria with regards to the three sustainability issues: environmental, social and economic; and (3) to identify aspects or opportunities for future improvement.

2. Comparative review of green building evaluations

To gain an understanding of previous comparative studies on green building evaluation, a total of 21 literatures published from 2006 to 2015 were reviewed. We aimed to identify: (1) which green building evaluation standards are most popular among comparative studies and (2) what the purposes of comparative study are. LEED was studied the most among standards followed by BREEAM, CASBEE, GREEN MARK, BEAM, GREEN STAR, GBTool, GBI, and ESGB. LEED and BREEAM often were selected as the basis for comparisons. CASBEE and GREEN MARK were the most studied standards from Asia. A total of 7 comparative studies focused on assessing a specific issue such as energy, passive design, lighting design, water and waste management. Other literatures were comparing existing standards in order to create a new evaluation standard of their own. Evaluation standards from the industrialized nations were studied more than those from the developing countries. It must be noted that most research on finding similarities and differences among standards did not look into weighting scores of each criterion.

3. Research methodology

A comparative method was used for analyzing contents in order to highlight similarities and differences among evaluation standards. This study adopted the research procedure offered by Wu et al. [7] in comparing green building standards.

3.1. Selection of green building evaluation standards

Wu et al. [6] and Waidyasekara et al. [7] suggested 3 criteria that could be used as a guideline for selecting green evaluation standards;

- Relevance: Some countries have more than one evaluation standard to assess different types of building. For instance, BREEAM has assessment methods for new construction, communities, existing and refurbishment building and home [8]. To fulfill objective of this paper, green evaluation standards for new construction was selected.

- Availability: Selected evaluation standards need to be available in order to get necessary detail requirements for comparison and the source can be either from the standard own websites or peer review journals.

- Measurable: Evaluation standards must have associated scores or assigned credits for each criterion, so that it is measurable for quantitative comparison.

In this study, nine (9) green building evaluation standards were pre-selected. Being the world’s first evaluation standard, the Building Research Establishment Environmental Assessment Method (BREEAM) was chosen. LEED is the most widely used green building rating system in the world [9]. DGNB came from Germany, which is home of Europe’s largest real estate sector. GREENSHIP, GBI, BERDE, GREEN MARK, LOTUS and TREES are all from ASEAN, which is the third largest economic in Asia and the world seventh largest [10]. All of standards are intended to be used to assess new buildings. The majority of evaluation standards assess buildings by giving points or credits when meeting criteria and adding scores into a total sum to determine rating levels. After reviewing each system with the selection guideline, four evaluation standards were chosen from developed countries and five are considered from developing countries.

3.2. Classification and analysis

There are some similarities and differences in criteria among evaluation standards. For the purpose of comparison BREEAM [8] main evaluation criteria were used as the overall framework. Its criteria compose of ten main categories: (1) Management, (2) Health and Wellbeing, (3) Energy, (4) Transportation, (5) Water, (6) Material, (7) Waste, (8) Land Use and Ecology, (9) Pollution, and (10) Innovation. All other countries criteria are identified and reorganized in relation to BREEAM's main and sub-categories. Assessments that cannot be classified under one of mentioned main criteria are put under "Other". Such an organization of information allowed for analyzing the major or minor focus of each standard.

The classified main and sub criteria help identify the key distribution and correlation with the three pillars of sustainable development: environmental, social and economic. The result would reveal how the evaluation standard balances the 3 key sustainability pillars. Criteria may be applied to more than one pillar of sustainability due to their relevancies.

3.3. Emphasize evaluation criteria

Because each country developed green building evaluation standard for its own specific climate and cultural context, assessment criteria, relative importance of the environment categories, and documentation requirements for certification are different [7]. To identify and compare most important criteria between each evaluation standard, assigned score or weight need to be properly calculated. Wu et al. [6] used the relative significance index (RSI) to compare waste management requirements in different green building rating systems. Three (3) categories of RSI were proposed based on different scoring systems: (i) the total point without section weight, (ii) the total point with section weight and (iii) the final ranking by comparing the number of fit items with the benchmarking number [10]. Two proposed RSI were adopted and modified to suit this study.

LEED, GREENSHIP, GBI, BERDE, GREEN MARK, LOTUS and TREES are in the first category. RSI is calculated by accumulating scores without using section weights. The RSI of each criterion is calculated by the following equation, Eq (1).

$$RSI = Si/TP*100 \qquad (1)$$

Si = the assigned scores of criterion, and TP = the total points of the system.

BREEAM is in the second category. RSI is calculated by accumulating scores using section weights. RSI of each criterion is calculated by the following equation, Eq (2).

$$RSI = (Ci/Cj)*Wj*100 \qquad (2)$$

Ci = the assigned credits of criterion i, Cj = the total credits of the corresponding section j, Wj = the weight of the corresponding section j.

DGNB's score is comparable to RSI.

4. Green building evaluation comparison results

4.1. Overview of the chosen green evaluation standards

- BREEAM (Building Research Establishment Environmental Assessment Method) was created by BRE (Building Research Establishment) in 1990 [8]. This was the first green building evaluation standard. BREEAM for new construction consisted of 52 individual assessment issues within 10 categories

- LEED (Leadership in Energy and Environmental Design) is a voluntary green building evaluation standard that was developed in the United States by the USGBC in 2000. LEED certification for New Construction was divided into eight main categories [11].

- DGNB was created by the German Sustainable Building Council (DGNB) that was founded in 2007 and the German Federal Ministry of Transport and Construction and Urban Development. The objective was to create environmental compatibility, resource-friendly and economical environments that safeguard the health, comfort and performance of their users [12].

- GREENSHIP is an assessment tool that was developed by Green Building Council Indonesia (GBCI). GBCI is an independent institution, which advocates and organizes familiarization activities using principles of green, ecological, and sustainability in the planning, implementation and operation of buildings and its environment in Indonesia [13]. This tool is divided into six areas.

- The Green Building Index (GBI) is an environmental rating system for buildings developed by Malaysian Institute of Architects and The Association of Consulting Engineers Malaysia. GBI is Malaysia's first comprehensive rating system for evaluating the environmental design and performance of buildings based on the 6 main criteria [14].

- BERDE (Building for Ecologically Responsive Design Excellence) was lunched by The Philippine Green Building Council (PHILGBC) in 2010. The buildings were evaluated based on 11 main criteria [15].

- Green Mark, established by the Building and Construction Authority (BCA) of Singapore in 2005, has certified over 1,180 projects in Singapore. Green Mark is organized into 5 categories and 28 sub-categories [16].

- LOTUS is a set of market-based green building evaluation tools that was developed by the Vietnam Green Building Council specifically for the Vietnamese built environment. LOTUS evaluation system is based on various international green building rating systems [17]. LOTUS has 10 main and 55 sub evaluation criteria.

- TREES (Thailand) The Association of Siamese Architects under Royal Patronage and the Engineering Institute of Thailand under Royal Patronage jointly set up Thailand green building agency and later called Thai Green Building Institute [18]. The assessment is categorized into 8 main criteria and 51 sub evaluation criteria [19].

Table 1. RSI Comparison of criteria among green building evaluation standards

Main Criteria	Total %	BREEAM	LEED	DGNB	GREEN-SHIP	GBI	BERDE	GREEN MARK	LOTUS	TREES
Energy	24%	14%	24%	10%	25%	25%	8%	61%	26%	23%
Health and Wellbeing	12%	14%	15%	17%	7%	17%	6%	3%	9%	20%
Management	10%	11%	7%	22%	6%	18%	13%	3%	8%	5%
Water	10%	6%	10%	2%	24%	10%	6%	11%	13%	7%
Land Use and Ecology	9%	9%	11%	8%	10%	8%	17%	4%	11%	6%
Material	9%	13%	10%	8%	12%	6%	5%	7%	11%	10%
Waste	6%	7%	2%	16%	3%	3%	10%	4%	9%	5%
Transport	6%	8%	7%	3%	4%	3%	16%	2%	3%	5%
Pollution	6%	9%	6%	1%	6%	4%	6%	2%	6%	9%
Innovation	4%	9%	5%	0%	0%	6%	9%	4%	0%	6%
Other	4%	0%	4%	14%	3%	0%	2%	0%	5%	5%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Year lunched		1990	1998	2008	2009	2010	2005	2012	2010	2011

4.2. Comparison of criteria in different green building evaluation standards

A comprehensive comparison of 9 green building rating systems used in both developed and developing countries was conducted. While each of the standards emphasizes different issues and requirements for their particular locations, they share many similarities and are dedicated to promoting the construction and operation of sustainable buildings.

RSI highlights the most important criterion in the standards—an important evidence for our comparative analysis. Table 1 presents a comparison of reclassifying mains and sub criteria to BREEAM format. There are total of 80 sub evaluation criteria spreading over 11 main categories. The outcomes of the comparison are described below:

- Management; This criterion focuses on project management issues from the initial project brief stage to design stage, procurement, building commissioning, occupancy and onto the appropriate provision of aftercare services. When comparing weighing score across 9 standards, DGNB emphasizes this criterion more than the others. GREEN MARK only gives RSI of 2.5%.

- Health and Wellbeing; This criterion concerns comfort, health and safety of building occupants, visitors and others within the building as well as its surrounding. Failure to provide conditions that satisfy the majority of occupants would impact productivity due to excessive discomfort. Unhealthy buildings that would result in an increased morbidity and expose occupants to illnesses are unacceptable [20]. Thailand's TREES allocates nearly 20% of its total credits to Health and Well-being category. GREEN MARK gives far less emphasis to this criterion.

- Energy; energy used in buildings is significant and obviously the key concern with regard to global warming [20]. Due to its significant impact on the environment, energy efficiency design has the largest proportion of credits distributed amongst the environmental criteria. The specification and design of energy efficiency, systems and equipment need to support energy conservation in buildings' design and operation [9]. LEED, GREENSHIP, GIB and LOTUS allocate one fourth of its' total scores to energy issues. Buildings could earn up to 61% of the total score in GREEN MARK. Energy efficiency equipment has the highest weighting score in this energy criterion.

- Transportation; this criterion rewards thoughtful decisions about building location that encourages better access to sustainable means of transport and amenities for building users. This section emphasizes the accessibility to public transport and other alternative means of transportation that reduce car journeys and, therefore, lower congestion and CO2 emissions over the building lifespan [8]. BREEAM and LEED give higher scores on transportation criteria when comparing with other standards but still less than BERDE.

- Water; conservation of fresh water is one of the most distressing issues globally. This criterion is based mainly on an "efficiency first" approach to water conservation [21]. Reducing potable water use (internal and external) over building lifespan and minimizing losses through leakages are the main concerns of this criterion [8]. GREENSHIP gives one fourth of the total score to water-related issues. DGNB gives only minimal attention while both GBI and LEED give similar weighing scores on this water criterion of 10%.

- Material; this criterion encourages steps to reduce the impact of construction materials through design, construction, maintenance and repair. As a result, embodied energy and other environmental impacts associated with the extraction, processing, transport, maintenance, and disposal of construction materials will be reduced [21]. BREEAM, LEED, GREENSHIP, LOTUS and TREES give more than 10% of their total weighting score to material-related category. The comparison shows that the evaluation standards from the developed nations are more concerned about life cycle impacts than those in the developing countries.

- Waste; this criterion encourages sustainable construction management, waste minimization during operation, maintenance and repairs [8]. By emphasizing good design and construction practices, wastes from construction and building operation could be minimized and therefore reducing the amount of waste to landfills. It recognizes measures that aim to reduce future wastes from building renovations. DGNB emphasizes and gives high scores of 16% on this criterion and on the other hand LEED gives only 2%.

- Land and Ecology; the criterion emphasizes the essential relationships between buildings, ecosystems, and ecosystem services. This criterion aims to encourage sustainable land use, habitat protection and creation, and improvement of long-term biodiversity for the building's site and its surrounding land [30]. BERDE emphasizes this issue more than other standards.

- Pollution; natural risks, harmful substances, hazardous emissions, lighting and air pollution are all deemed important in the evaluation of building environment [22]. The prevention and control of pollution and surface water run-off associated with building's location and use are addressed in this criterion. BREEAM and TREES give relatively high scores of 9% when comparing with other evaluation standards.

- Innovation; in order to encourage and recognize exemplary performance in all sustainable aspects, such as procurement strategy, design feature, management process or technological development, this criterion provides opportunities to earn scores for such endeavors. Six out of ten green building standards give scores for such an achievement.

- Others; many sub criteria cannot be categorized under above-mentioned criteria. LEED, BERDE, LOTUS and TREES provide scores for issues that respond to the local needs. DGNB give scores for design issues. Local job creation can also earn points from LOTUS.

The comparison of main criteria among the 9 green building evaluation standards has been shown in Table 1. BREEAM, LEED have high RSI on both health & wellbeing and energy. The majority of the evaluation standards set high priority on the energy criteria while DGNB aims at management sensibility. BERDE gives RSI of 17% to land use and ecology criteria and 16% to transportation criteria. GREEN MARK gives more than half of its' total score to energy criteria. Beside energy, GREENSHIP put heavy emphasis on water and material while giving less on waste issues. On the contrary, DGNB gives high RSI to adaptability of functions in waste criteria and only gives about 2% of its total score to water criteria. For waste criteria, 6 out of 9 evaluation standards give RSI of less than 5%.

4.3. Criteria comparison using the 3 pillars of sustainability framework

Since the 3 pillars of sustainability (environment, social and economy) are equally vital to sustainable development, ideally, evaluation standards should evenly cover all three dimensions. This section presents the relative weights (RSI) given by the evaluation standards in relation to sustainability. The score distribution among environment, social and economy aspects implies levels of emphasis in a standard among three pillars of sustainability. Criteria were evaluated and assigned to the highest impact aspects in the sustainable concept. Some criteria may be included in multiple aspects because they straddle between boundaries. For example, criteria related to human comfort were considered as a social issue because it impacts human well being as opposed to economic [23]; at the same time energy efficient equipment belong to both environmental and economic issues because it reduced energy consumption, which affect the environment as well as cost of energy. In theory, each evaluation criteria should touch on sustainability concept equally that mean all three should have 100% RSI. Table 2 reviews RSI contribution of each green building evaluation standard toward sustainability.

After reviewing RSI of each criteria in detail, 90%, 79% and 43% are the average of RSI that have been allocated into the 3 pillars of sustainability, i.e., environmental, economic and social issue respectively. The RSI represents how well each standard has covered sustainability concept. DGNB has 73% in the environment-related weight criteria which is the lowest RSI among the evaluation standards. TREES, GREENSHIP and LOTUS have RSI below the average. GREEN MARK has only 17% RSI for weight criteria relating to social issues. Eight out of 9 standards give strong emphasis on environmental issues while DGNB focus on economic.

Table 2. Comparison of RSI distribution among 3 pillars of sustainable development concept

Description	Average RSI	BREEAM	LEED	DGNB	GREENSHIP	GBI	BERDE	GREEN MARK	LOTUS	TREES
Environment	90%	88%	92%	73%	93%	98%	80%	98%	92%	93%
Economic	79%	80%	79%	91%	72%	83%	78%	86%	70%	73%
Social	43%	50%	47%	43%	37%	36%	59%	17%	41%	54%

5. Discussions

The balance of environmental, economic, and social aspect is the overarching goals of sustainable developments. Green building evaluation standards were created based on this drive. Even though each standard has been developed based on local conditions and environmental problems, its assessment criteria can reflect sustainable development framework. Results of this study show that the environmental dimension is the most concerned in all evaluation standards, similar to the findings by Berardi [24] and Poveda [25. However, the lack of an integrated assessment approach has led to a disproportion among the 3 dimensions of sustainability.

All green building standards have been developed with criteria to suite a country's needs and requirements to reflect the issues of greatest importance in their contexts. Regardless of the local conditions, energy efficiency remains the key measure in most standards. Increasing energy consumption and releasing CO2 from the construction industry affect energy efficiency requirements [26]. Importing natural gas as fuel for most power generators [27], Singapore's GREEN MARK gives 61% of RSI to energy while the average RSI on this category is 24%. Meeting GREENSHIP's water conservation criterion alone can earn RSI up to 24%. This implies that water problem is one of major issues in Indonesia. Water is an essential resource for any nation development and quality of life. It is recognized that any changes or decision made during design or planning phase were the most economical and effective to building performance [28]. German admitted this fact and reflected in its green building standard by giving RSI of 22% to management criteria. Exposure to natural disasters in the Philippine was ranked 3rd behind Vanuatu and Tonga respectively in the world [19]. Urbanization and environmental degradation play a significant role in increasing incidences of natural disasters [29]. These problems may have contributed to the focus on land use and ecology criteria than other criteria in BERDE.

6. Conclusion

This paper summarizes a comparative study of 9 green building evaluation standards, 3 from western countries and 6 from ASEAN. All selected standards were investigated to pinpoint relative significance index.

The comparison revealed that energy was given the highest weight because energy has been a major concern for most nations despite of contextual differences. Some nations such as Singapore put energy far more important than other criteria while Indonesia emphasizes water issue. With respect to the 3 pillar of sustainability, the environmental dimension has the most detailed criteria and hence receives the highest weight, followed by economic and social dimension. In addition, environmental related criteria that were categorized under energy, resources and ecology shows that the resource issue received the least weight when comparing with energy and ecology issues. Upon examining how these criteria were assessed, it was found that intention of evaluation standards were, by and large, on preventive measures, averting wastage from occurring such as using energy efficiency appliances, good design for building envelop, suitable site selection, protection of ecological features and pollution prevention. Despite the fact that building materials consume large amount of energy and released CO2 during manufacturing, transporting and installing [30] and its waste volume is an environmental burden, the assessments on waste minimization performance were not clearly emphasized. Notwithstanding, the waste section within evaluation standards include management aspect after waste being generated.

The finding from this comparative study suggests that to achieve the balance of three sustainability pillars, future development of green building evaluation standards need to emphasize two specific areas: firstly, include measures that recognizes social impact and secondly, change from reactive measures for material resource management to proactive measures to encourage reduction and efficient use of virgin materials. Pressure on the natural resources will increase with economic expansion and growing population. Resources are limited in relation to the growing demand; some countries run the risk of critical scarcity in the near future. Minimization material consumption by far is the most effective method [31] since it means less resource will be extracted, and therefore, lower CO2 emission during extraction, production and recycle process.

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BEHAVIORAL AND PARAMETRIC EFFECTS ON ENERGY CONSUMPTION THROUGH BIM, BEM, AND ABM

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Abstract

Over the past years, several tools and methods have been developed to address performance-related designs and provide designers with integrative platforms to estimate building energy consumption and mitigate its impact. However, the predictions obtained through different energy modeling engines have been typically deviating from the actual energy consumption. As such, many efforts have attempted at bridging this so-called “performance gap. Nonetheless, this was conducted in a fragmented fashion whereby synchronizing the geometric exchange of Building Information Modeling (BIM) to Building Energy Modeling (BEM) was done independently from incorporating, through Agent-Based Modelling (ABM), building occupants’ behavior vis-à-vis energy consumption. Therefore, this paper merges the aforementioned approaches and presents work targeted at assessing the diverse and dynamic energy-use behavior of occupants using BIM, BEM and ABM. To that end, a simulation environment was developed to study both the parametric design and behavioural factors. The design parameters included within a BIM model were utilized to set the thermal zone, the internal zone gains were defined using ABM, and resulting data was exported as an input data file to EnergyPlus. Several experiments have been conducted for the case of an academic office and results of the energy analysis highlighted a variation of up to 11% as compared to static occupant behavioral patterns generally adopted.

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Keywords: ABM; BIM; BEM ; energy; simulation;

1. Background

In recent years, the debate surrounding BIM and BEM has been aggregated by the widely accepted “performance gap”. The efforts to bridge this gap were channeled towards synchronizing the data exchange between the architectural model and the energy model. According to Hyun et al. [1], BIM can play a key role in improving the consistency of construction information related to building energy analysis. Through the use of BIM, the process of creating an energy model can be easily automated. Consequently, geometry and other assumptions detailed in the architectural model remain consistent and are not subject to interpretation or improper simplification. Furthermore, BEM has always relied on performance-based compliance paths, whereby a building’s proposed design must not exceed the energy consumption of a similar reference building modeled with the prescriptive inputs from the code [2, 3]. For example, ANSI/ASHRAE/IES Standard 90.1-2016 [3] provides trade-off schedules and densities for occupancy, lighting, equipment, and thermostat set points for different types of buildings. However, and given that each building has its unique features and operational conditions, codes and standards fail to provide a realistic schedule tailored to each building. On that account, design engineers (i.e. architects or service consultants) fail to notice the connection between building technical features (e.g. volume, orientation, shading devices, etc.) and the behavioral patterns and operating profiles of the occupants. The aftermath is two spatially competing models, BIM

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vs. BEM, that ignores the complexity that occupants' behavior add to the estimation of building energy consumption activities [4-7]. In addition to energy-behavior synergy, recent studies in commercial and residential buildings have concluded that the behavior of occupants within an indoor environment has a dual effect on both the overall building energy use and occupants' satisfaction with the indoor environmental quality (IEQ) [2, 8]. Prone to this give-and-take relationship between energy and comfort, researchers no longer have the luxury to treat occupant-related variables as boundary conditions; in other words, making default assumptions about occupants' behavior in energy modeling is bygone [9]. As such, the process of simulating occupant behavior has been gaining an increasing attention in recent simulation research with several methods being implemented to mimic occupants' behavior in buildings. For instance, Nassar and Elnahas [10] used the random walk approach to assess the topology of space design in terms of occupants' movement. Furthermore, Virote and Neves-Silva [11] explored the applicability of stochastic models to represent the space occupancy and the occupant's behavior. On the other hand, ABM has been widely used to simulate the interaction of occupants with their environment and with other agents [12-15] and has proven very promising in reflecting occupant's sensation, perception, inference, and interaction. For instance, Lee and Malkawi [13] used ABM to allow agents to adapt to their environment by making reasonable behavioral decisions based on their comfort. Similarly, Barakat and Khoury [14] employed an agent-based framework to study occupant multi-comfort level for building energy optimization.

From what has been presented, some efforts attempted at coupling the two spatially competing models, BIM and BEM, but this was conducted in a fragmented fashion whereby synchronizing the geometric exchange of BIM to BEM was done independently from incorporating, through Agent-Based Modelling (ABM), building occupants' behavior vis-à-vis energy consumption. Therefore, this paper presents a holistic framework targeted at assessing the diverse and dynamic energy-use behavior of occupants using BIM, BEM and ABM. The contributions of the research presented in this paper thereby lie in : (1) creating a BIM model of the office space that employs the visual programming language (VPL) to automate the parametric and behavioral data exchange with BEM and ABM respectively, (2) developing an agent-based model (ABM) whereby an autonomous agent interacts with its environment and makes behavioral decisions based on thermal and visual comfort levels, 3) documenting the behavioral decisions and exporting them to the BEM model to generate annual energy consumption, and (4) validating the proposed BIM-BEM-ABM framework by comparing simulated results with results obtained from a survey conducted with occupants of the same environment as the one simulated.

2. Methodology

In order to achieve the objectives of this research study, the proposed methodology addresses issues in two main task areas, namely: (1) Design and implementation of a thermal and visual environmental survey, and (2) Development of a BIM-BEM-ABM framework using Revit-Dynamo, EnergyPlus, and Anylogic.

2.1. Satisfaction Survey Design and Implementation

Satisfaction surveys are invaluable diagnostic tools used to provide detailed insight into the building daily operations through occupant feedback. In this study, the purpose behind conducting a thermal and visual environmental survey is to directly acquire about the occupants comfort levels, which can be used as a verification tool in the modeling part. As such, a thermal and a visual satisfaction survey is constructed following the guidelines provided in ANSI/ASHRAE Standard 55-2013 [16] and is divided in three sections. The first section includes general information pertaining to the room number, desk number, and type of controls available in the given space (e.g. window shades, thermostat, light switches). In the second section, the occupants are asked to report their overall thermal and visual experience on a 7-point semantic differential scale with choices ranging from -3 (very satisfied) to +3 (very dissatisfied). In the event where respondents vote dissatisfied to either of the visual or thermal subsections, they are then asked to move to the third section. In this latter section, respondents are asked about their expected behavior towards their dissatisfied/discomfort state (i.e. visually dissatisfied, thermally dissatisfied hot, and thermally dissatisfied cold) given four control features (switches, shades, thermostat and clothing insulation level). If an occupant opts to adjust the thermostat, he/she is then asked to input the set-point that would adjust their thermally dissatisfied state.

In this study, an open space office, having a total floor area of 120m^2 and a height of 4m, was surveyed in a medium-size academic office building (Figure 1). The space counted 18 occupants with a response rate of 83%;

exceeding the rate set by ANSI/ASHRAE Standard 55 [16] (80% for under 20 solicited occupants). However, as the sample size surveyed is considered small, 15 additional occupants were surveyed from an adjacent office that has the same spatial characteristics. The probability of occupants satisfied was then predicted by dividing the number of votes falling between "just satisfied" and "very satisfied," by the total number of votes.

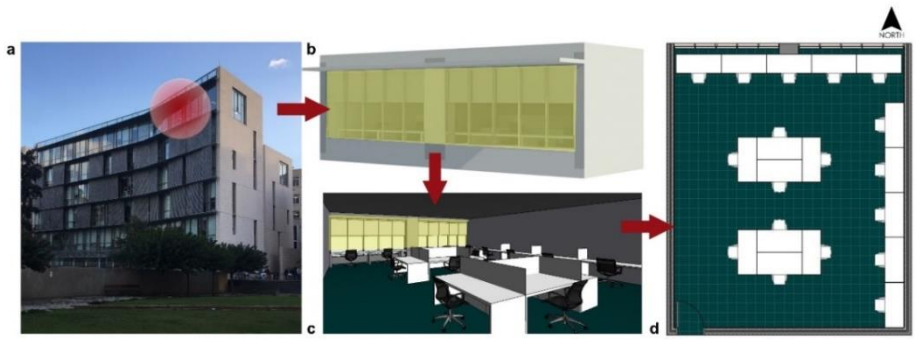

Fig. 1. (a) Actual office building; (b) Revit model for the selected office; (c) Internal camera view; (d) Internal space distribution.

2.2. BIM-BEM-ABM Framework Development

Conventionally, extracting input data from BIM for energy modeling has been relying on two main methods; namely the Industry Foundation Class (IFC) and the Green Building XML (gbXML) [17, 18]. However, users of these methods have little control over how data files are created or loaded. To address this, Visual Programming Language (VPL) has been introduced to the BIM-BEM spectrum [19]. VPL allows novice users in programming to create computer programs by building visual relationships between elements within a user friendly interface [20]. Accordingly, this part of the paper builds on previous work that presented a graphical visual programing interface, DynamoPlus, to induce BIM-BEM interoperability[22]. Yet, this data extraction covered only the geometric aspect while the dynamic occupant integration with the building system had to be assumed according to an energy code. Therefore, this paper challenges the aforementioned interface and presents a holistic approach targeted at assessing the diverse and dynamic energy-use behavior of occupants using BIM, BEM and ABM (Figure 2).

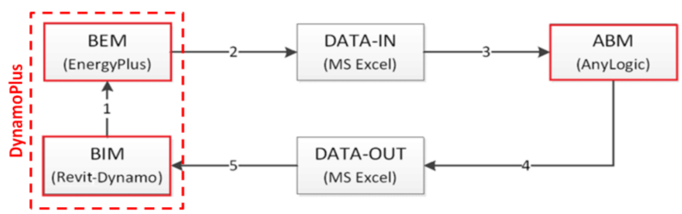

Fig. 2. BIM-BEM-ABM framework.

The first step towards setting up this trinity starts by building an architectural BIM model (Figure 2). Next, with reference to Hajj-Hassan and Khoury [22], DynamoPlus works on creating three major "Objects" for the simulation engine, EnergyPlus, namely the "Zone Definition, Zone Loads-Internal Gains, and Zone Loads-Outdoor Air [22]. The second step initiates the first energy run from EnergyPlus (i.e. step 2 in Figure 2). In this case, six input data files (IDF) [22] are created in order to generate the required data/input needed to run the ABM model (i.e. step 3 in Figure 2). More specifically, the thermal and illumination environmental factors are simulated for a whole year (8760 hours) to determine the mean radiant temperature (tr), natural daylighting lux, and glare index. Furthermore, each of these parameters (tr, lux, and glare) were obtained with respect to two behavioral decisions, "shades on" or "shades off", at a specified reference point in the Revit model, which in our case was the working level around the center of the space. The second energy run is initiated after ABM exports the behavioral parameters as "DATA-OUT" into an Excel sheet (step 4 in Figure 2). At this stage, a new graph is added to the 'DynamoPlus' architecture (i.e. step 5 in Figure 2). The graph reads the exported data from ABM and lists them in a syntax readable by EnergyPlus. The rationale behind this step is the ability of the VPL, employed by the BIM component, to transform time-dependent input parameters into schedules that contain occupant behavioral decisions at different time intervals. Hence, the generic "IDF" file that was generated according to default schedules described by the user or ANSI/ASHRAE/IES Standard 90.1-2016 is now redefined to include additional schedule-related "Objects", particularly "ScheduleTypeLimits", "ScheduleCompact", and "ZoneControl:Thermostat". Understanding how these "Objects" operate in conjunction with the overall energy simulation environment is key to generating realistic results that mimic real-life scenarios; another shortcoming encountered when resolving energy simulation interfaces and plugins [23].In fact, this group of objects allows the user to influence scheduling of many items (such as occupancy density, lighting, thermostatic controls) and to control the switches and shades status at each time step. For the first object, discrete numeric values were set as "control type schedules" for the thermostat, internal shades, and switches. Besides formulating an energy model based on the simulated behavior of occupants, a baseline building design was modeled to ASHRAE 90.1 prescriptive requirements as a reference building. The goal behind developing such a reference building was to compare it with the pre-set schedule assumptions' sensitivity to changes in occupancy-related behaviors and ultimately shed light on some of the shortcomings of occupant modeling requirements in the above mentioned energy code. In this model, the thermostat temperature set-points are defined as shown in Figure 3, the Daylighting:Control object is used to determine how much the electric lighting can be reduced, and the shades are modeled to be lowered when the solar transmitted energy exceeds 100 watt/m^2 and then remain lowered for the rest of the day.

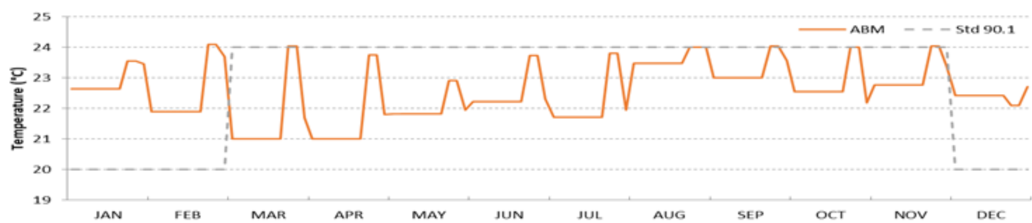

Fig. 3. Typical day/month for simulated behavior of thermostat set-point.

It is worth noting again that the BEM framework component aims at creating an energy model that calculates the energy consumption of the selected office space. Additionally, the methods used to formalize the EnergyPlus "Objects" are highlighted to explain the transformation of time-dependent ABM parameters into schedules that contain occupant behavioral decisions at different time intervals. According to ASHRAE Standard 169-2013 [24], the climate zone for the area under study (i.e. Beirut, Lebanon) is "2A" which is defined as Hot–Humid. The weather file used for the simulation was obtained from the National Center for Environmental Information (NCEI) and is based on a Typical Meteorological Year (TMY) for years 1993 to 2016 [25]. The values for the different envelope components were provided by building operators and are summarized in Table 1. The glazed surface is oriented towards the North with a window to wall ratio (WWR) of 0.9 and an external shading device with a projection factor (PF) of 0.45.

Table 1. Building Envelope requirements

Opaque Elements U-values	Fenestration Elements
Roof = 0.49 w/m2k	Assembly U-value = 3.04 w/m2k
Mass wall = 0.45 w/m2k	Assembly SHGC = 0.55
Floors = 0.6 w/m2k	Assembly Min VT/SHGC = 1.2

Another framework component warranting some further discussion is the aforementioned multi-comfort ABM model that was created using Anylogic, a java-based software that allows the user to develop custom Java codes and integrate them in prebuilt simulation blocks[27]. A prerequisite for the ABM model consists of conceiving a whole-body thermal-balance comfort (WBC) model to predict thermal comfort. This model predicts the thermal sensation (predicted mean vote, PMV) and percent dissatisfaction (predicted percent of dissatisfied, PPD) for a group of people based on measurements of the physical parameters in the environment[28]. On the contrary, no adequate human visual comfort model is found to support consensus-based design recommendations[29]. Accordingly, visual comfort was assessed on the basis of meeting a minimum horizontal illumination of 500 lux while not exceeding a discomfort glare index (DGI) of 21 [30, 31]. Once the comfort principals were put in place, the multi-comfort ABM model was then realized (Figure 4) with two primary objectives: (1) Predict and verify the probabilities or likelihood of occupants choosing actions that were examined in the satisfaction survey and (2) Export the learning process of the representative occupant as schedules to the BEM model.

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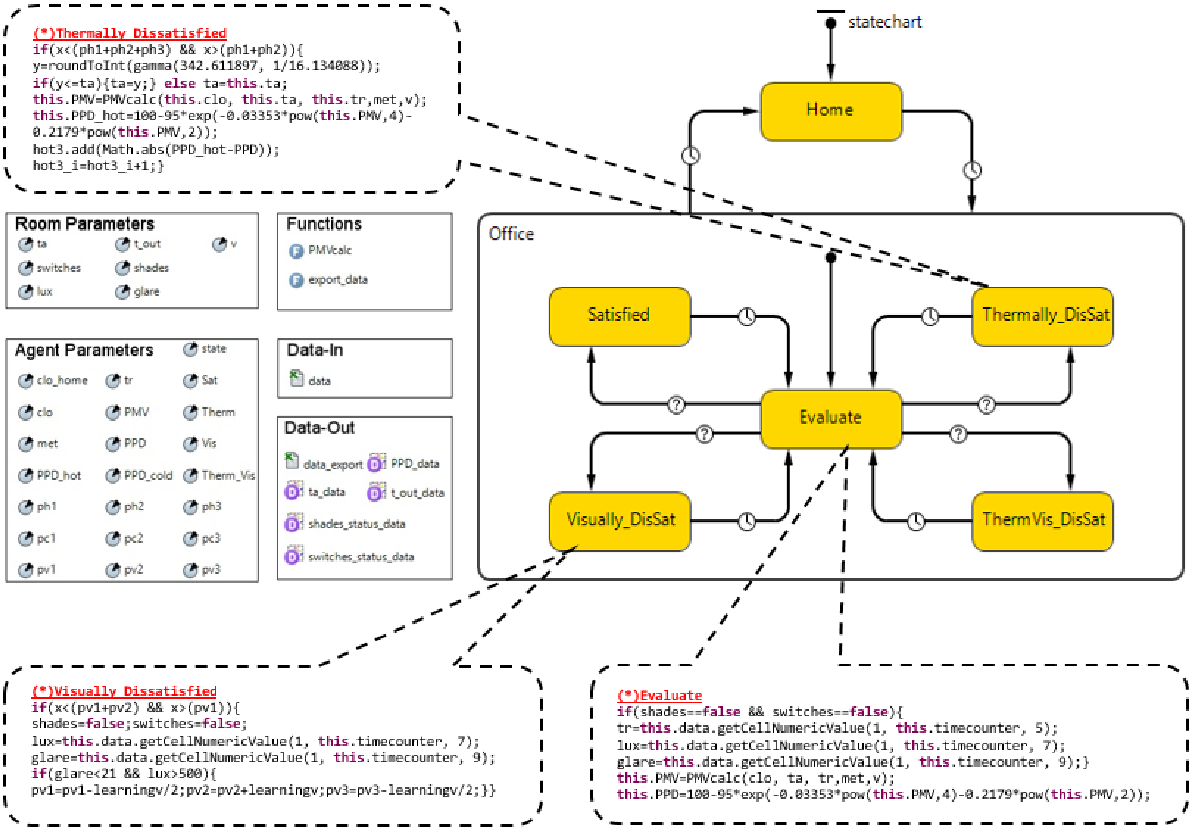

Fig. 4. Multi-Comfort Occupant Agent State-chart

The simulation takes place over a whole year while taking into consideration the effect of each month on the pre-set thermostat temperature and the occupants' choice of their initial clo-level (clo_home) at the beginning of each day. The thermostat temperature for each month is based on the requirements set in ANSI/ASHRAE/IES Standard 90.1 (Figure 3). The clo_home parameter, shown in Figure 4 under Agent Parameters, is determined for a representative occupant as a function of outdoor air temperature at 06:00 a.m. (Figure 5). The clo levels are adjusted to higher values to account for dress code adopted in Lebanon and as described in ASHRAE-55 clothing ensembles. Additionally, one of the important assumptions considered in the modeling process is the use of a representative occupant to account for all the occupants present in the office space. This is considered acceptable due to the following: (1) ASHRAE-55 states that, when the WBC method is used and occupants are free to adjust their clothing in response to the thermal conditions, it is feasible to assume a single representative occupant with an average clo-level value representing multiple individuals [16], (2) as several occupants working in the chosen office space are considered to have a metabolic rate around 60W/m^2, common to office reading, writing, and typing activities, it is thereby suitable to assume a single representative occupant with an average metabolic rate value representing multiple occupants, and (3) the learning behavior of the representative occupant is based on decreasing the PPD which is the index that establishes a quantitative prediction of the percentage of thermally dissatisfied people.

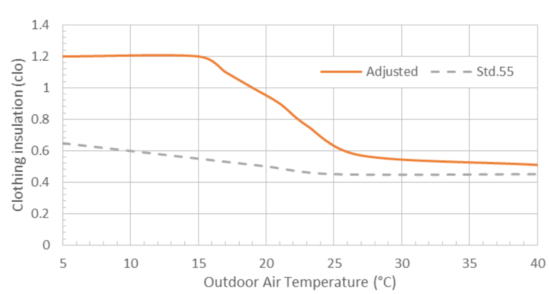

Fig. 5. Adjusted and ASHRAE'Ss Std. 55 representative clothing insulation as a function of outdoor air temperature at 6:00 a.m.

Carrying on, each day starts at 8:00 AM and ends at 6:00 PM with Saturdays and Sundays excluded from the simulation process. The time unit for the model is selected to be hours with two agents, occupant and room. The occupant agent adjusts its overall state (i.e. satisfied, thermally dissatisfied, visually dissatisfied, or thermally/visually dissatisfied) based on the room parameters (e.g. thermostat set-point, lux level, etc.) and probabilities of actions taken by the agent. Figure 4 depicts the statechart of the occupant agent in particular. In this case, two main states exist, Home and Office. In the home state, the agent performs no actions and waits for 14 hours before it is allowed to enter the "Office" state. Once in the office state, the agent starts transitioning between different internal states. These transitions are either time-triggered or condition-triggered. The agent first enters into the "Evaluate" state to determine its current thermal and visual comfort level and then calculates the PPD. The comfort levels are determined from the parameters read from the "DATA-IN" sheet (Figure 2). Given the overall state, the agent then exits with a condition-triggered transition to any of the other internal states. For example, if the |PMV|> 0.5 and lux>500, the agent enters the "Thermally_DisSat"state. In this new state, the agent decides whether it is dissatisfied thermally hot or cold and then takes actions based on initial pre-set equal probabilities, in this case 33%. After taking an action, the occupant agent determines the benefit obtained by calculating the difference between the initial and final PPD. This helps the agent develop a learning behavior that decreases the overall percentage of dissatisfied and accordingly adjusts the probabilities. The agent stays for 1 hour in the state "Thermally_DisSat" before it is allowed to exist back to "Evaluate" and the cycle resumes for 8760 time steps.

3. Experimental Results and Discussion

Survey results (Table 2) show that 23% of occupants are thermally dissatisfied whereas 17% are visually dissatisfied – a reasonable outcome given that the office building is oriented towards the north (Figure 1). Moreover, the number of occupants taking specific behavioral actions to adjust their comfort level were categorized and counted as shown in Table 2.

Table 2. Percentage of occupant/agents taking specific actions when thermally and visually dissatisfied.

Actions	Survey Values	Simulation Values	
		Mean	SD
Thermally Dissatisfied (Hot)			
ph1: Clo-level & Thermostat-set point	63.3%	65.3%	1
ph2: Clo-level	20%	16.5%	0.47
ph3: Thermostat-set point	16.7%	18.2%	0.92
Thermally Dissatisfied (Cold)			
pc1: Clo-level & Thermostat-set point	20%	21.9%	0.7
pc2: Clo-level	57%	55.3%	1.18
pc3: Thermostat-set point	23%	22.8%	0.68
Visually Dissatisfied			
pv1: Switches On & Shades On	53%	45%	2.89
pv2: Switches Off & Shades Off	7%	8.6%	0.7
pv3: Switches On & Shades Off	40%	53.6%	2.88

It was found, that occupants tend to choose between three options when they are thermally dissatisfied. They would either: (1) adjust their clothing insulation (clo-level) and thermostat set-point (ph1 or pc1), (2) adjust only their clo-level (ph2 or pc2), or (3) change the thermostat set-point (ph3 or pc3). Furthermore, when visually dissatisfied, occupants tend to choose between three different options related exclusively to the shades and switches statuses. The probabilities of occupants choosing each of these actions are also presented in Table 2. As shown, 63.3% of occupants choose "ph1" when thermally dissatisfied during a hot weather. However, in a cold weather, the majority of occupants (57%) choose only to adjust their clo level.

On the other hand, the framework simulated results came very close to the values obtained from the satisfaction survey conducted in the open space office environment (Table 2). Additionally, the dynamic behavioral patterns shown in Figure 6 were obtained from the ABM model in the form of logged data and converted into typical daily schedules over 12 months. These patterns are a representation of the simulated values for PPD and Thermostat set points. Thirty simulations were logged and used to estimate the building energy consumption in each run. The histograms for the simulated satisfied hours and building energy consumption are presented in Figure 7. Moreover, a Shapiro-Wilk test failed to reject the null hypothesis that the data came from a normally distributed set. A right tailed t-test was then used to compare the true mean of the simulated set with that of the reference building's total, cooling, and heating energy consumption (e.g. 106.39, 62.28, and 17.96 GJ/yr respectively). In this case, the following null hypothesis was tested: "the mean difference between the true and reference value is zero" and the alternative hypothesis was set as: "the true mean of the simulated set was greater than the reference energy values". As the p-value obtained for all three tests was 2.2e-16, which is less than the chosen confidence level (0.05), the null hypothesis was rejected. Accordingly, there is sound evidence that the energy consumption as a function of occupant behavior is greater than that of the static occupant behavioral patterns adopted by the current energy codes.

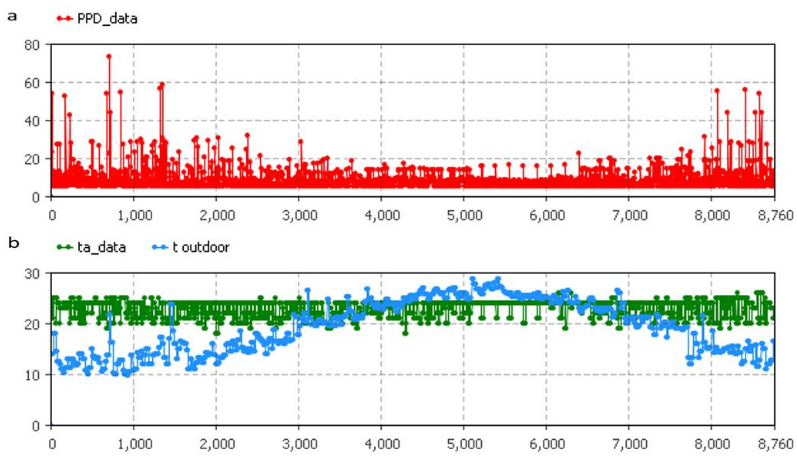

Fig. 6. (a) PPD and (b) Thermostats set-point simulated values over the whole year.

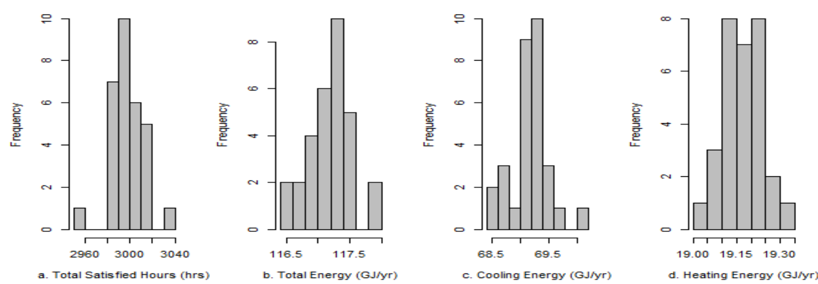

Fig. 7. Histograms of simulated (a) Total satisfied hours, (b) Total Energy consumption, (c) Cooling energy, and (d) Heating energy.

4. Conclusion and Future Work

The set of models discussed in this paper are an attempt at simulating the impact that occupants may have on a building in terms of energy consumption. In particular, the ABM model presents a novel approach towards predicting the probabilities of actions that occupants might select to enhance both of their visual and thermal comfort levels. As a matter of fact, the simulated results came very close to the values obtained from the satisfaction survey conducted in an open space office environment. Additionally, the paper constitutes an eye-opener for practitioners adopting occupant modeling requirements from current codes and standards, emphasizes the fact that static schedules do not represent all building types, and is considered a major contributor to the performance gap between simulated and measured energy use. Moreover, another contribution lies in addressing the performance gap via a BIM-VPL interface that acts as a communicating hub between BEM and ABM. The final emulation of this array of models was documented on an office space with the energy analysis results highlighting variations with up to 11% as compared to static behavioral patterns generally adopted. Future research is needed to cover other IEQ factors such as air quality and acoustics and cover different categories of occupants. Additional work is needed as well to study the effect of different building parameters on energy vs. comfort optima. Such studies will look to test the validity of the proposed models in accounting for different technical aspects of a building including orientation, skin treatment and material selection.

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Collusion and bid rigging in the construction industry: case studies from Poland

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Abstract

Polish economy experienced significant changes during the past 30 years. System transformation that began in the 1980's and was enhanced by Poland's entry to the European Union in 2004 significantly influenced economic development. Apart from tough history experiences, they formed the shape of national economy which can be observed nowadays. It was a long and difficult process. During political and economic rapid changes greater numbers of price collusions and other illegal practices can be observed than during the stable development of national economy. Authors selected and reviewed the most important anti-competitive cases in the construction industry from the past 30 years in Poland. The review includes not only cases that were officially justified and penalized - like the collusion of portland cement big producers - but also cases of collusion suspicion on highway and express roads that ended with acquittal court verdicts.

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Keywords: bid rigging ; case study ; cement cartel ; collusion ; collusion detection ; highway ; public tender ; road;

1. Introduction

Anti-competitive agreements are not a new practice in economy. The idea of price fixing performed by producers is simple and was already present in antiquity. Since ages, there have been attempts to establish laws and codification rules, which were to assure fair regulation of production rules and price fixing on the market. The oldest known case of an anti-competitive agreement [1] is the price fixing of Athenian grain importers in 388 BC. The problem of collusion and bid rigging has been a subject of many studies, i. a. [2–10]. Construction industry, including road construction is an important and capital-consuming branch of world economy. The authors want to strongly emphasize that the evaluation of collusion occurrences recalled in this paper is based strictly and limited to publicly available documents: court verdicts, prosecutor's investigation data and public tender announcements. The authors by no means express personal judgement concerning collusion occurrence.

2. Price fixing among cement producers

Cement industry is characterised by little flexibility among cement buyers. Consequently, the rise of cement prices usually does not cause consignees to purchase substitutes, for there is no such substitute with identical properties as cement which could replace it as a component in concrete production. Price increase in sales of cement significantly influences the price of concrete. However, it does not cause a relevant change in concrete and cement demand. The market is dominated by large cement producers. The manufactured product is homogenous and undergoes periodic laboratory testing in order to maintain its performance properties required by law. The possibility of new enterprises entering the market is hugely restricted due to necessary significant expenditure towards production machines and due

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to the limited access to raw materials. All above mentioned reasons lead to a tendency among producers to establish anti-competitive agreements, in particular recurrent collusions [11], irrespective of a country, political system and existing legislation. The number of producers usually remains the same before and after the time of collusion. It is confirmed by multiple cases of global infringements and cement cartels operating in Poland during the interwar period, at the end of 1980s and in the years 1998-2009.

Cement industry in Poland has undergone substantial changes in the 1990s. Its privatisation took place at the beginning of political transformation and the biggest international companies such as Lafarge, Heidelberg, Dyckerhoff, CRH, Miebach and RMC became operational on the market. In the following years, these companies consequently strengthened their market position through methodical takeovers and restructuration of acquired plants. Before the transformation, there were at least 21 existing cement plants on the Polish market. As a result of the consolidation of the sector and the transformations performed inside corporate groups, there were at least 13 already existing cement plants and 1 newly launched on the national market in 2006. A significant number of closed plants possessed overexploited manufacturing elements and their production capacity was noticeably low. These are some of the reasons why new investors decided to either close or convert them into transhipment terminals. The modernization would have been not cost-effective. The political transformation led to a change in the legal rules of cooperation among cement producers in Poland. As a result of privatisation processes, large international companies took ownership of Polish enterprises and became competing entities in the realm of free-market economy.

The transformation process had an impact also on Polish associations comprising companies from cement and limestone industry. Such associations had existed on the market under different brand names since many years: The Cement, Limestone and Gypsum Industry Association (until July 1982), The Binding Construction Materials Industry Enterprises Association and The Cement and Limestone Producers Association, which in June 2005 changed its name into The Cement Producers Association [SPC]. All enterprises participating in the cement collusion of 1998-2009 were members of SPC. As history has shown, most cement producers decided to prevent or minimalize the results of their own financial deterioration in the view of transformation and returned to the centrally planned economy period's status quo of price fixing and manipulation of economic activities.

According to The Office of Competition and Consumer Protection [UOKiK], *"The President of the Office has found that the largest cement producers in Poland have been dividing the market at least since 1998, fixing permitted shares for respective entities, as well as prices of cement, levels of price increases along with their dates and order of introduction. For this purpose, they shared confidential information, i.a. on the volume of completed sales. The fixing was being performed on numerous meetings, both multi- and bilateral, at the level of board chairmen and commercial directors. The investigation showed that even if not all cartelists were present at a meeting, decisions were being conveyed to those absent. There was an established coordinator who exchanged information relevant for the cartel functioning with designated representatives of other cement plants. Cases of pursuing individual sale policies or misleading other members of this illegal agreement also appeared during the long-time cartel existence. However, such attempts were being immediately condemned and severely punished by the collusion parties".* As shown in the above mentioned quote, the mechanism of illegal fixing was professionally organised. Public services could not find any hard evidence based on phone records, for cement producers' telephone contacts (some of which made from separate pre-paid mobile phones) were in principle limited only to agreeing on the meeting point. The entrepreneurs were brought down during the police raid whatsoever. It was discovered that the conspirators named themselves (sic!) 'Group G7'. Case evidence included i.a. tables, spreadsheets and paper notes found during the inspection in the companies' headquarters [12,13].

A pure coincidence contributed to the collusion exposure. In 2005, during the distribution of greenhouse gases emission allowances performed by the Ministry of the Environment, it was discovered that levels of actual cement production were much higher than it followed from data delivered by the producers. Mutual deceit within the "Group G7" was the cause of these differences: Cemex lowered its actual cement production level by ca. 0,6 million tonnes. Literature indicates that cartels are by its very nature unstable, because of permanently occurring incentives leading to inside deceit among the parties. In practice, deceit is an inherent feature of cartel operation. Entrepreneurs, who establish and then break anti-competitive agreements are often likely not to abide by reciprocal deals. It is worth mentioning that the extent of Cemex's underestimation equalled to ca. 4,76 % of the entire cement production in Poland in 2005 – which is a relatively high number. Other cartelists were "honest" among "Group G7" at least in this aspect, namely, they delivered actual data concerning levels of sold cement. The cement cartel was well organised. Cemex's underestimation of data regarding cement production triggered the necessity of punishment for this entity imposed by other collusion members, and future compensation for the damages suffered so far. Calculations and simulations were performed. Consequently, after negotiations, an agreement was reached, pursuant to which Cemex must have lowered its sell and declared an increase of prices. The cooperation within cement cartel was not only about the exchange of information. It was a meticulously planned, long-term process, lasting at least since 1998, and its inherent part was an attempt to permanently stabilize the shares of individual entrepreneurships existing on the market. The establishment of particular shares for each collusion member occurred through references to 'historic' quotas of cement production of individual producers in the times of centrally planned economy.

The period of cement collusion in Poland can be divided into another two periods. Period 1 (lasting until the end of 2002), when the entrepreneurs exchanged information among each other through The Cement Producers Association, being in a sense the continuation of the pre-transformation system. Period 2 (after 2002), when economic information was not conveyed to SPC, but rather to an outside party bound by confidentiality provisions: The Law and Industrial Property Office 'Optimas'. The hiring of an outside entity was expected to create a formal structure, compliant with the competition law. In reality, there was also an existing "parallel system". The exchange of information among members of the cartel was happening at two levels. Firstly, within the law, through The Office 'Optimas'. Secondly, and unlawfully, through SPC or directly among each other. Coordinators responsible for the information exchange were being nominated from each entity and they were being frequently replaced.

The UOKiK decision provides information on some of the procedures of services concerned with economic crime detection. Operational swiftness and effective coordination are very important factors allowing for securing evidence which directly points towards anti-competitive malpractices. In the discussed case, some details suggesting the prevalence of collusion, such as e.g. additional notes found alongside certain columns, the dates of file modification or the occurrence of the name "Group G7" proved to be essential for the investigation. During UOKiK's inspection in the Ożarów Group headquarters, representatives of the Office found direct evidence of collusion. It was a protocol of the meeting of the Group Board, in which a following statement was found: *"There is a chance of increasing the prices in the next year's first quarter. However, talks on the executive level of individual groups are needed"* [12]. Such a document was introduced in the Group's headquarters in Warsaw and became missing shortly after. A separate group of UOKiK's officials was in control of the second headquarters of this group in Karsy town but the above mentioned quote was not found in protocols there. The Office found that the Board Office Manager had hidden the page with controversial notes, then edited the file in the computer by deleting the notes and introduced the printed protocol as complete. After a police technician performed an 'undo' procedure in the open file, the previously deleted notes appeared again. This example proves how important is quick and unannounced action during investigations run by antitrust services and offices. The employees, faced with stress related to the investigation process, may get caught off guard and deliver sensitive documents which might be impossible to retrieve at a later stage.

As a consequence of exposing the collusion, cement producers were financially penalised with fines amounting to PLN 339 million. Levels of the fines for individual cartel members oscillate between 5 to 10 % of the revenue figure of the penalised company from one year preceding the collusion exposure. The collusion lasted for at least 12 years. The cement industry revenue figures in Poland from 2007 amount to PLN 6,8 billion, with a total production at a level of 17 million tonnes and a price of PLN 400. This implies that if cement prices had been extortionate by 10 %, the estimated loss of consignees in the twelve-year period of competition law infringement might have equalled to ca. PLN 8,2 billion.

3. Suspected bid rigging in road construction industry

Social and economic fallout of bid rigging in road construction is particularly dangerous for the society because of the induced deadweight losses of large size. Anti-competitive actions of these agreements' members always lead to price increase in road building. However, in case of the roads of significant importance for the country, was the collusion to remain unproven, the suspicion itself might bring higher social and economic losses than the sheer existence of undetected collusion. Whenever the road is built and made available within deadlines, the society is financially disadvantaged only in terms of the contract prices being higher than on the not abused market. Conversely, in the event of collusion suspicion and a long term investigation (or an investigation closure due to lack of evidence), social and economic costs might bring more harm upon both public treasury and individuals.

3.1. Expansion of national road 8 on the stretch Jeżewo-Białystok (collusion suspicion)

The results of the tender *'Expansion of national road 8 to the two-lane expressway parameters on the stretch Jeżewo – Białystok'* were announced on June 6th, 2009. The winner was a consortium of companies: Mota Engil, Strabag and Transprojekt Gdański, with an offered price of PLN 675 million gross. The runner-up was the consortium of Mostostal,

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Budimex-Dromex, Bilfinger Berger and Arcadis, offering a price of PLN 699,2 million gross. The third and last competitor was the consortium of PBDiM Mińsk Mazowiecki, Astaldi and Dro-consult, offering a price of PLN 703,4 million. The Internal Security Agency [ABW] suspected the occurrence of an agreement upon the offered prices during the bidding process. Recorded phone calls of the companies' managers, which implied colluding in a verbal code, were to be used as evidence. According to ABW, repeated references of "*room 698*" made by Strabag's director in the recorded phone calls indicated that the offer of Mostostal and Budimex Dromex consortium could not have been lower than PLN 698 million in order to enable the win of Strabag's consortium. In exchange for such agreement, the above mentioned consortium was expected to win the tender for the reconstruction of national road 8 on the stretch Piotrków Trybunalski - Rawa Mazowiecka [14]. The accused companies did not agree with the lawsuit's contents. The court acquitted all 11 defendants. The prosecutor appealed against the sentence but it was overruled [15,16]. Eventually, GDDiKA withdrew the lawsuit.

3.2. Expansion of national road 8 on the stretch Piotrków Trybunalski - Rawa Mazowiecka (collusion suspicion)

The results announcement of the tender for a state contract *'Design and expansion of national road 8 to the two-lane expressway parameters on the 61 kilometres long stretch Piotrków Trybunalski - Rawa Mazowiecka'* took place on March 17th, 2009. The winner was a consortium of companies: Astaldi, PBDiM Mińsk Mazowiecki, PBDiM Erbedim, Intercor and Technital with an offer of a gross value of PLN 1734 million. Second place belonged to the consortium comprised of Budimex-Dromex, Mostostal Warszawa, Bilfinger Berger and Arcadis, offering a gross price of PLN 1771 million. The third and last bidder was a consortium of entities from the corporate group named Strabag, Mota Engil Poland and Transprojekt Gdańsk with a gross price of PLN 1910 million but this offer was rejected by the ordering party due to inconsistencies with Terms of Reference. It was found during the investigation (based on The Internal Security Agency [ABW] surveillance) that Mostostal might have acquired information about the tender details from the director of the Warsaw department of General Director for National Roads and Motorways (GDDKiA). The information might have been passed to the consortium members. Transcripts from the recorded phone calls indicate that values of the offers might have been agreed upon among the companies beforehand. However, after the opening of the envelopes it became clear that the winning consortium was the one with Astaldi (theoretically not participating in the collusion). According to the media reports, the winning consortium ordered phone surveillance from an outside provider on its own member: Erbedim, suspecting it of collusion with another consortium. According to the phone transcripts, an offer price of PLN 1860 million gross was established within the consortium led by Astaldi. This information was passed to Mostostal by the director of Erbedim which might have enabled the offer adjustment. Astaldi, suspecting the leak, lowered the price to PLN 1734 million gross, not notifying Erbedim, and won the tender, which came as a surprise for the second in line consortium and Erbedim itself [17,18]. After the announcement of the tender results, the companies decided to create no more consortia in the existing configuration. For the tender was won by another consortium (unsuspected of bid rigging), new opinions appeared, stating that the companies' foreign headquarters communicate within the highest ranks, irrespective of Polish managers [19].

At the end of 2016 GDDiKA filed a lawsuit against Budimex Dromex, Mostostal Warszawa and Bilfinger Berger. GDDiKA demanded PLN 539,9 million by way of compensation for the usage of prohibited 'concerted practice', meaning 'the replacement of autonomous economic decisions with arrangements performed within competing entities submitting biddings for the same public tender' [20]. The accused companies did not agree with the lawsuit's contents. The court acquitted all 11 defendants. The prosecutor appealed against the sentence, but it was overruled [15,16]. Eventually, GDDiKA withdrew the lawsuit.

3.3. Construction of motorway A4 Radymno-Korczowa (collusion suspicion)

On September 7th, 2009 the opening of envelopes with bidding offers concerning the contract *'Design and construction of motorway A4 Rzeszów – Korczowa on the 22-kilometer stretch Radymno (without the hub) – Korczowa'* took place. The tender was won by a Greek company J&P Avax, which submitted an offer of PLN 818, 5 million gross with a 120-months warranty and the expiry date of the tender validity period set for 30th April, 2012. According to ABW, it might have been a case of anti-competitive agreement between Strabag and its competitors: MSF Polska, Autostrada Wschodnia, Mostostal Warszawa, Budimex-Dromex and DTP Terrassement. The collusion expected all offers to be no higher than PLN 951 million and the process of misinforming the ordering party about the prices included in offers. The accused companies did not agree with the lawsuit's contents. The court acquitted all 11 defendants. The prosecutor appealed against the sentence but it was overruled [15,16]. Eventually, GDDiKA withdrew the lawsuit.

3.4. Construction of junction between motorway A4 (Krzyż hub) with regional road 977 (collusion confirmed with a court sentence)

The results of the public tender concerning *'Construction of junction between motorway A4 (Krzyż hub) with regional road 977'* were announced in 2010. The winner was a consortium of companies: Mota Engil, Strabag and Poldim. The investment was finalised in 2012 and cost PLN 41,5 million. Following its completion, an investigation was pursued. It was concluded that a collusion between competitors had occurred and the case was referred to the court [21]. In the meantime, the city of Tarnów must have returned PLN 14 million of the European Union grant due to the risk of the necessity to return the entire sum. The suspicion of collusion arose whilst investigating another investment: the construction of a tram line in Cracow. It was the information provided by one the collusion members who offered his testimony in exchange for an extraordinary mitigation of punishment [22] that proved decisive for exposure and resolution of the case. It was established during the investigation that three of the consortium members came into agreement with their competitors. Pursuant to the agreement, they were expected to either submit much higher price offers or withdraw from the tender [23]. Individuals from the ordering party – Tarnów Public Transport Authorities, closed in January 2012 - also participated in the collusion. The anti-competitive agreement entered into force and its members exchanged illegally acquired funds among each other. The fiscal control showed that the legalisation of the funds was performed through issuing invoices for fictitious services or fake construction protocols. Performed analysis and expertise estimated that the ordering party suffered losses of PLN 25,8 million (the amount of the winning bid overestimation) as a result of the collusion. In 2016, a settlement was reached. Mota Engil and Strabag agreed to pay PLN 31,7 million to Tarnów City County by way of compensation. In May 2016, The District Court sentenced 14 defendants of this case to suspended detention and heavy fines. In another legal proceedings of the same case, The Regional Court sentenced ex-president of Tarnów for corruption and abuse of power to five years of detention, ten-year prohibition for holding executive positions in local authorities and a fine of PLN 295 000 by way of compensation to the city.

3.5. Construction of motorway A1 Częstochowa - Pyrzowice, stretch H (collusion suspicion)

The tender results of a contract for *'Construction of motorway A1 Tuszyn – Pyrzowice, stretch H, Zawodzie hub (without the hub) – Woźniki (hub included)'* were announced in February 2015. After the opening of the envelopes, the tender committee declared that the cheapest offer of PLN 532,8 million gross was submitted by Intercor. The winner did not provide a deposit and did not prolong the tender validity period, therefore it was excluded from the competition whatsoever. What is more, six other companies were excluded from the tender and their offers rejected. In result, the subsequent offer was chosen – a consortium of two companies from the Strabag corporate group, offering a price of PLN 574,5 million gross. GDDiKA suspected a bid rigging agreement between the competitors and the case was presented to the prosecution [24]. Eventually, the investigation was dropped on account of the lack of data proving the commitment of a crime [25].

3.6. Construction of the bypass of Olsztyn (collusion suspicion)

The tender results of a project *'Construction of S51 Olsztyn – Olsztynek on the stretch Olsztyn East – Olsztyn South'* were announced in April 2015. After the opening of the envelopes, the tender committee declared that the cheapest offer of PLN 548,9 million gross was submitted by Bilfinger [25]. The winner did not provide a deposit, hence it was excluded from the competition. The subsequent offer (the consortium of companies Intercor and Most) was rejected due to the lack of consistency with the specification. The offer third in line (the consortium of companies Salini, Todini and PBDiM Kobylarnia) was found abnormally low and rejected. Salini filed an appeal to The National Appeals Chamber (KIO) but the appeal was rejected as well [24]. Ultimately, the winner of the tender was Budimex with an offer of PLN 913 million gross. The investigation was eventually dropped due to the lack of data proving the commitment of a crime [25].

3.7. Extension of national road 8 on the stretch Przeszkoda – Radziejowice (collusion suspicion)

The full name of this contract is *'Extension of national road 8 to the two-lane expressway parameters on the stretch from the hub with the voivodeship road 579 in Radziejowice to the hub with voivodeship road 721 in Wolica; Task I: the project continuation and expansion of national road 8 to the two-lane expressway parameters on the 9,9 kilometres long stretch Radziejowice – Przeszkoda'*. After the opening of the envelopes, the tender committee declared that the cheapest offer of PLN 306,9 million gross was submitted by Strabag [24]. In this competition there were also other participating companies: Bilfinger, Mirbud, Mostostal Kraków, Metrostav and Gulermak. The tender for the adjoining stretch Przeszkoda – Paszków was won by Intercor (offer of PLN 436,7 million gross), whilst neither Strabag nor Budimex participated in this tender [24]. The investigation was eventually dropped due to the lack of data proving the commitment of a crime [25].

3.8. Construction of the bypass of Góra Kalwaria along national roads 50/79 (collusion suspicion).

After the opening of the offers, the tender committee declared that the cheapest offer of PLN 267, 8 million gross was submitted by Bilfinger [24]. The winner did not prolong the period of deposit validity, hence was excluded from the competition and the consortium of companies Intercor and Planeta took its place with an offer of PLN 313,7 million gross. Mirbud, in third place and with an offer of PLN 329,0 million gross filed an appeal to the National Appeals Chamber. The Chamber recognised the appeal and rejected the winning offer of Intercor and Planeta. However, the rejected competitor filed a complaint to the District Court, which found the complaint legitimate and substantiated. The investigation was eventually dropped due to the lack of data proving the commitment of a crime [25].

3.9. Summary

The above mentioned cases of contracts suspected of bid rigging became the subject of three bigger, separate court or prosecution proceedings. The first investigation dealt with tenders related to national road 8 on the stretches Jeżewo-Białystok and Piotrków Trybunalski-Rawa Mazowiecka. In accordance with the existing laws, an exposure of price collusion might be a basis for withholding or withdrawing of public funding obtained also from European Union grants, irrespective of the ordering party's participance in such practices. As a result of an investigation led by ABW, European Commission withheld the PLN 3,5 million subsidy payment until the investigation would have become dropped. It is a particularly interesting case in the light of likelihood that one of the members of the collusion (Erbedim) was passing information to the competing consortium [14,17,18]. Hypothetically, it may have caused the failure of the collusion, hence proving its existence became impossible (lack of the losses on the side of ordering parties). Differences between the prices known from the recorded phone calls and the factual submitted offers (even though relatively small) were another factors indicating the lack of collusion. The second investigation was related to motorway A1 Częstochowa – Pyrzowice on the stretch H, the bypass of Olsztyn, national road 8 on the stretch Przeszkoda-Radziejowice and the bypass of Góra Kalwaria. On the grounds of the collusion suspicion, the prosecution started an investigation which was later dropped due to the lack of evidence justifying the suspicion of crime commitment. The third investigation concerned only one tender related to the junction of motorway A4 and voivodeship road 977. (Only this investigation can be acknowledged as a proven case of bid rigging, as only in this case the acquired evidence allowed for a conviction rendered by the court. Comparison of the case studies was presented in table 1 below.

Table 1. Comparison of selected public tenders for road construction in Poland 2009-2017

Selected road tenders announced between 01.01.2009 and 30.06.2017 in Poland	Collusion existence	Winning company/consortium	Why collusion was suspected	How the case finished
Expansion of national road 8 on the stretch Jeżewo-Białystok	Collusion suspicion	Mota Engil, Strabag and Transprojekt Gdański	Recorded phone calls of managers	Court acquittal, appellation overruled, lawsuit withdrawn
Expansion of national road 8 on the stretch Piotrków Trybunalski - Rawa Mazowiecka	Collusion suspicion	Astaldi, PBDiM Mińsk Mazowiecki, Erbedim, Intercor, Technital	Recorded phone calls of managers	Court acquittal, appellation overruled, lawsuit withdrawn
Construction of motorway A4 Radymno-Korczowa	Collusion suspicion	J&P Avax	Recorded phone calls of managers	Court acquittal, appellation overruled, lawsuit withdrawn

Construction of junction between motorway A4 (Krzyż hub) with regional road 977	Collusion confirmed	Mota Engil, Strabag and Poldim	Connection to other investigation and confession of collusion member	Court convictions to suspended detention and heavy fines
Construction of motorway A1 Częstochowa - Pyrzowice, stretch H	Collusion suspicion	Strabag	Rejection of 7 offers including the initial winner	The investigation dropped due to lack of collusion evidence
Construction of the bypass of Olsztyn	Collusion suspicion	Budimex	Rejection of first 3 offers	The investigation dropped due to lack of collusion evidence
Extension of national road 8 on the stretch Przeszkoda – Radziejowice	Collusion suspicion	Strabag	Not natural offerors behavior on adjacent road tenders	The investigation dropped due to lack of collusion evidence
Construction of the bypass of Góra Kalwaria along national roads 50/79	Collusion suspicion	Intercor and Planeta	Rejection of the winning offer	The investigation dropped due to lack of collusion evidence

The introduced cases of public tenders in the Polish road construction industry prove that swift exposure and proof of bid rigging is difficult. Acquiring direct and hard evidence of collusion is even more difficult, regardless of phone surveillance and other operational techniques. Out of 8 examined contracts suspected of anti-competitive collusion, only once the collusion was confirmed by a court sentence, which allowed for punishment of its members and damage payments towards the ordering party (table 2). In the remaining 7 cases, relevant public services performed investigations and did not find any bid rigging occurrences.

Table 2. Summary of number of public tenders for road construction suspected for collusion in years 2009-2017

	Number of tenders (pcs)	Part of total (%)
Estimated total number of tenders (value higher than PLN 10 000 000)	>= 1000	100 %
Free from collusion suspicion	992	99,2 %
Collusion suspicion but not proven	7	0,7 %
Collusion confirmed and proven by court sentence	1	0,1 %

4. Other cases of price collusions – Oriented Strand Boards, gutters, aggregate

Another example of the infringement of competition law is an agreement between producers of particle boards and fiberboards used in construction: Kronospan Szczecinek, Kronospan Mielec, Pfleiderer Group, Pfleiderer Group, Pfleiderer Wieruszów and Swiss Krono [26]. During the investigation proceedings, UOKiK concluded that above mentioned entrepreneurs colluded on price fixing and the exchange of commercial information (dates of price hikes, revenue figures) regarding wood-based panels. On December 21th, 2017 UOKiK issued a decision recognising such practices lasting until September 9th, 2011 as anti-competitive and imposed fines [27]. The usage of the punishment mitigation programme by Swiss Krono contributed to the exposure of collusion as it simplified the process of gathering strong evidence of verbal price fixing and information exchange.

Based on the media reports, it may be concluded, that in the period of last several years in Poland there were other cases of infringement or alleged infringement of competition laws among following group of entrepreneurs: aggregate and asphalt suppliers, gutter and abrasives producers [28,29] and other construction materials suppliers.

5. Summary and conclusions

The authors of this paper conducted a review with regard to cases of suspected anti-competitive practice and cases confirmed by court sentences. Effective exposure and penalisation of such practices is difficult and requires swift and coordinated action. There is no one universally-applicable method. Combinations of various methods prove most successful, i.a. scientific and economic studies [30], artificial intelligence [6–8], statistical analysis, hard evidence (e.g. wiretapping and surveillance), demonstrating factual losses of ordering parties, 'leniency' programmes.

Existing market environment, concentrations between undertakings, type of activity, as well as economic transformations, large events affecting the demand for quick infrastructure expansion (e.g. accumulation of EU aid schemes or organisation of global sports events) – all these influence the possibility of anti-competitive agreements.

The lack of providing effective proof of bid rigging in road construction industry, which is a subject of this paper, does not have to mean that the price collusion did not appear at all.

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Comparative Review of Assessment Methodologies of Building Embodied Energy

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Abstract

According to a report of UNEP, the building sector accounts for 40 percent of the total energy consumption in the world and is related with 33 percent of global greenhouse gas (GHG) emissions. During the whole life cycle of a building, the total energy consumption can be classified in two categories: embodied energy and operational energy. Operational energy means the energy consumed by a building to support its operation and maintenance； while the embodied energy is defined as the energy consumed in producing of a building, including the building material production, on-site delivery, and construction. Plenty of efforts have been devoted into the reduction of the energy consumption through the operational phase, however, there is a controversial about the evaluation methodology of embodied energy due to the lack of regulation or uniform standard. Currently, there are three prevailing methodologies to assess the building embodied energy: Process analysis, Output-Input analysis, and Hybrid analysis. The measurement procedure, requirement of database, system boundary, labour and time input as well as the evaluation result are all different. The evaluators need to select the suitable methodology to achieve their evaluation objectives. With the aim to give out a reference for the selection of methodology, a comparative review is conducted to compare the advantages, disadvantages, and feasibilities of the three methodologies; and the appropriate methods for different regions in the world are also pointed out.

Keywords: Embodied energy, LCA, Process analysis, Input-output analysis, Hybrid analysis

1. Introduction

According to a report of UNEP, the building sector accounts for 40 percent of the total energy consumption in the world and is related with 33 percent of global greenhouse gas (GHG) emissions [1]. To reduce the energy consumption of buildings has been a common task worldwide; therefore, governments, construction industries, as well as research institutions all have a strong aspiration to make out an accurate measurement of the energy consumption derived from the usage of a building. Normally, a building's life period will last for 30 years or even longer, depending on the design criteria in different countries. During the whole life cycle of a building, the total energy consumption can be categorized in two kinds: operational energy and embodied energy. Operational energy means the energy consumed by a building in the usage phase to support its necessary service, including heating, cooling, air ventilation and provide power to building facilities, which is relevant with the adoption of energy efficient technologies, the energy saving electrical appliances, the envelope insulations, the occupant behaviours, etc. During the past years of effort, a lot of goals have been achieved in the reduction of building operational energy. Governments set up objectives to reduce the energy consumption of existing buildings and promote new green buildings. For example, Hong Kong government made Energy Saving Plan for built environment, which sets for targets of 40% reduction of energy intensity by year 2025, as the base year of 2005, and reduce the electricity consumption by 5% from year 2015 to 2020; UK and European Commission initiated The Energy Performance Building Directive (EPBD) to improve the energy performance of building during operation phase[1]; in Australia, the implementation and mandatory disclosure of NABERS(National Australian Built Environment Rating System), along with more strict building regulations imposed by government in 2006 and 2010, have facilitated the adoption of energy efficiency technologies in commercial buildings and residential households.

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While so much effort has been devoted on reducing the operational energy, the relative proportion of embodied energy in the total building energy consumption in the life cycle becomes higher. Although a lot of research have been conducted to study the embodied energy, many issues are still indefinite. The first issue is the definition of embodied energy. Generally, embodied energy means that the energy consumed in life cycle stages of a building other than the operation (space conditioning, water heating, lighting, operating building appliances and other similar operational activities) [2], and the life cycle phased accounted to embodied energy include the production of building materials and components, the onsite construction, the post construction stages such as renovation and the final stages such as demolition and disposal [2, 3]. The whole life cycle of a building can be illustrated by Figure 1.

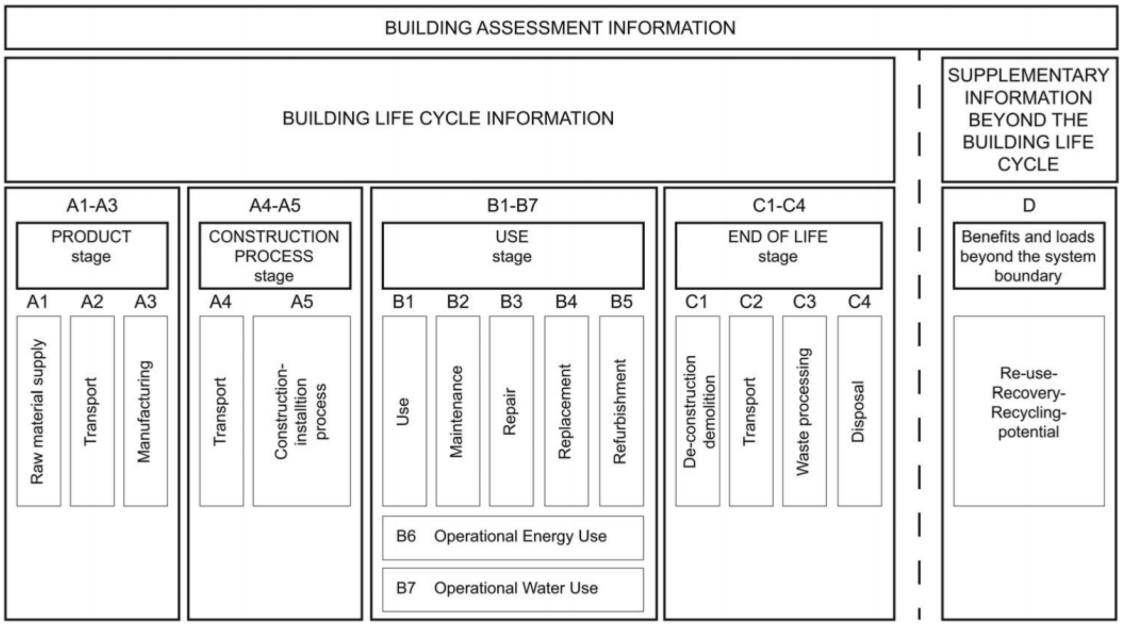

Figure 1 Life cycle stages from BS EN 15978:2011 Sustainability of construction works-assessment of environmental performance of buildings-calculation method [4]

The building lifecycle in Fig.1 can define five types of system boundary in embodied energy evaluation:

- System boundary type: Cradle to Gate:

This boundary includes only the production stage of the construction products integrated into the building. Processes taken into account are: the extraction of raw materials, transport of these materials to the manufacturing site and the manufacturing process of the construction products itself. Thus, in the case of a building the impacts of this stage are accounted for as the sum total of the "cradle to gate" impacts of its individual components.

- System boundary type: Cradle to Site:

Cradle to gate boundary plus delivery to the construction site.

- System boundary type: Cradle to Handover:

Cradle to site boundary plus the processes of construction and assembly on site.

- System boundary type: Cradle to End-of-Use:

Cradle to handover boundary plus the processes of maintenance, repair, replacement, and refurbishment, which constitute the recurrent energy and emissions. This boundary marks the end of first use of the building.

- System boundary type: Cradle to Grave:

The cradle to grave system boundary includes the "cradle to end of use" boundary plus the end of life stage with processes such as building deconstruction or demolition, waste treatment and disposal (grave).

Additionally, different scholars have different opinions and interpretations about the system boundary included into the embodied energy. Crowther and Upton both identify the embodied energy as the total energy required in the creation of a building, including the direct energy used in the construction and assembly process, and the indirect energy consumed to manufacture the materials and components of the buildings, which is in the respective of system boundary cradle to end of construction [5, 6]. In 2012, European Commission defined the embodied energy as the energy used in the production of materials and components, of which, the system boundary is in the respective of cradle to gate. In Knight and Addis's opinion, the embodied energy includes the energy consumed in the material production and transportation to site, of which, the system boundary is cradle to site [7]. Accounting of different system boundaries resulted to the various proportions of embodied energy in the total energy consumption, what is more, Nebel and Alcorn also pointed out the proportion of embodied energy in total life cycle depends highly on the geographic location and climate [8]. Because of so many uncertainties in the embodied energy assessment, the previous research came to various of conclusions about the range of embodied energy proportion. Sartori and Hestnes [9] took a literature survey on buildings' life cycle energy usage covering a total of 60 cases from nine countries and found out that the proportion of embodied energy is between 2-38% for a conventional building, and the minimum one is a university building in Michigan, USA [10]; the highest one is a Australian residential building[11]. For low energy buildings, this share could range from 9–46%, the minimum one is a residential building in Germany[12] while the maximum one is a residential apartment in Sweden[13]. Thormark also analysed the embodied energy of three Sweden low energy buildings and determined that the energy embodied in the building materials could be around 37–38% of the total life cycle energy [14].

The significant reason for the different proportions of embodied energy concluded by the previous studies is that up till now, there has not been a unanimous standard or protocol to measure the building embodied energy. The researchers choose different system boundaries and database in line accordance with their own objectives and perspectives. Life cycle assessment (LCA) is the core concept of embodied energy measurement, based on which, three methodologies are the most widely employed, including process based LCA, Input-output LCA, and hybrid LCA. A comparative review and discussion of the three methodologies are presented in this paper.

2. Life Cycle Assessment

Life cycle assessment (LCA) is the core thinking to measure the embodied energy of buildings. It is a systematic tool to evaluate the environmental aspects of a product, technology, or service by identifying and quantifying the energy and material uses and releases to the environment through all stages of its life cycle, which include extracting and processing materials; manufacturing, transportation, and distribution; usage, reuse, maintenance; recycling and final disposal. The International Organization for Standardization (ISO) has published LCA Standards ISO: 14040:2006 and ISO 14044:2006 to introduce the principles, methodological framework, requirements and guidelines of LCA[15, 16].

There are four main phases in a LCA study: Goal and scope definition, Inventory Analysis, Impact Assessment and Interpretation (see Fig. 2). The first phase (Goal and Scope) states the intention, objectives, functional unit, system boundaries, data requirements, assumption, and limitations, etc. The second phase (Inventory Analysis) involves data collection and calculation procedures to quantify relevant inputs and outputs of a product system. The data collection includes energy inputs, raw material inputs, other physical inputs, etc. as well as waste, emissions to air, discharges to water and soil, and other environmental aspects. The third phase (Impact Assessment) is aims at evaluating the significance of potential environmental impacts using the results of Inventory Analysis. The last phase (Interpretation) considers both findings from the inventory analysis and the impact assessment together to interpret the results and to recommend improvement measures.

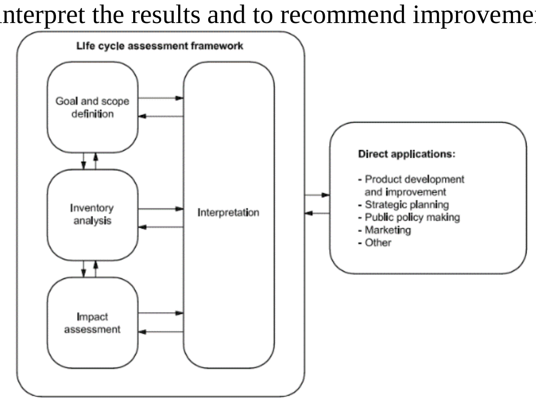

Figure 2 Stages of an LCA [16]

In the context of building embodied energy, LCA focuses only on the evaluation of energy inputs for different phases of the building life cycle only except the operational phase. Embodied energy of a building is the energy consumed by production of all the materials used in the building, including raw material extraction, material transportation, and manufacture; as well as the energy consumed during the period of erection/construction and demolition of the building. The embodied energy is made up by initial energy, recurring energy, and demolishing energy. Depending on the different system boundaries defined by evaluator, the detail components and resources of embodied energy is showed by Table1:

Table1: Components and system boundaries of embodied energy of building

			System boundary	Energy source
Building Embodied Energy	Initial energy	Material production	Cradle to gate	Extraction and processing of raw material; Assembly of products/components; Transportation between material factory.
		Construction	to site	Material Transportation to site; Construction activities on site; Disposal of construction waste.
	Recurring		to Renovation and maintenance	Replacement of material and component; Material Transportation to building; Maintenance activities; Transportation disposal material.
	Demolishing		End of life	Demolishing; Transportation.

The mathematical equation of initial and recurring embodied energy [17, 18]:

$$E_{initial} = E_{extraction} + E_{manufacture} + E_{construction} + E_{tranportation} \quad (1)$$

$$E_{material,i} = E_{extraction} + E_{manufacture} = \sum_1^i \alpha_i m_i \quad (2)$$

Where $E_{initial,}$ is the initial embodied energy of the whole building (in MJ); $E_{tranportation}$ is the embodied energy of the material or components transportation. $E_{material,i}$ is the embodied energy intensity factor for the i_{th} type of building material (in MJ/kg); and m_i is the mass of the i_{th} type of building material (in kg); and m_i should include not only the quantities of building material in-place but also the wastages incurred during construction; α_i is the embodied energy intensity factor for the i_{th} type of building material (in MJ/kg).

$$E_{tranportation} = \sum_1^i f_i m_i \, d_i \quad (3)$$

Where $E_{tranportation}$ is the embodied energy of the material or components transportation; f_i is the energy intensity of freight transportation in (MJ/ton km); m_i is the mass of the i_{th} type of building material in (ton); d_i is the transportation distance of the i_{th} material.

$$E_{construction} = \sum Q_j + \sum_1^r f_r w_r \, d_r \quad (4)$$

In the construction stage, the embodied energy mainly come from the usage of temporary of electrical power, the fuel for construction equipment, and the disposal of construction waste. Where Qj is the quantity of electrical or fuel energy consumption on the site, in MJ, f_r is the energy intensity of freight transportation in (MJ/ton km), w_r is the mass of the r_{th} type of construction waste in (ton), d_r is the transportation distance of the r_{th} waste.

$$E_{recurring,i} = [\frac{L_b}{L_i} - 1] \times \alpha_i m_i \quad (5)$$

$E_{recurring,i}$ is the recurring embodied energy of i_{th} material, L_b is the service life span of the building and L_i is the life span of the i_{th} building material.

3. Methodologies of LCA

The most frequently employed LCA methodologies are process based LCA, Input-output LCA and Hybrid LCA.

3.1 Introduction to Process based LCA, Input-output LCA and Hybrid LCA

Process based LCA

Process based LCA is a bottom-up technique. This method is based on data and information in the process of manufacture, from raw material extraction to production. When applying this method to measure the building embodied energy, the embodied energy databases for construction materials, material quantities as well as the specifications of building components are necessary.

This method is adopted by most of the regional or international LCA standards like ISO 14040, ISO 14044, EN 15804 (Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products); EN 15978 (Sustainability of construction works-assessment of environmental performance of buildings-calculation method), SETAC (Society of Environmental Toxicology and Chemistry), etc. And on the base of these international standards, like ISO, many LCA database and tools have been developed to provide user-friendly interface, which largely facilitate the evaluation process. However, one problem with process-based approach is the truncation error, for it is hardly to complete the whole production system of material, in the actual analysis, the information omission is unavoidable. Some previous studies pointed out that by process-based LCA, the incompleteness factor for building material is likely to be at least 10%, and there is also an opinion that nearly fifty percent of information will be lost in process analysis [3, 11, 19].

Input-output LCA

Input-output (IO) LCA is a top-down economic approach to estimate the life cycle environmental impacts of industry, because it uses sectoral monetary transactions data such as national input output table, the evaluation result of IO LCA is focusing on the industrial sector or even national economy. The rational of this methodology is input-output analysis, published by W. Leontief [20], and then his input-output analysis was updated and augmented by Hendrickson to develop Economic Input-Output Life Cycle Analysis (EIO-LCA). The EIO-LCA model uses economic input-output analysis matrices, and industry sector level environmental and non-renewable resource consumption data to assess to economy-wide environmental impacts of product and process [21, 22] . The input–output tables could determine the energy intensity of economic sectors and hence quantified the energy requirements of a product, based on its price [17]. Because the I-O-based intensities are obtained as the averages of relevant industrial sectors, this methodology suffers from a so-called ‘aggregation error’. It may incur large uncertainties in data as a result of its reliance on the assumption that all products within a sector share the same energy intensity per monetary unit [23]. This method is adopted by a standard developed by UNEP, Global Guidance Principles for Life Cycle Assessment Databases: A Basis for Greener Processes and Products.

Hybrid LCA

The hybrid LCA method combines the strengths of process based and Input-output. Treloar[24, 25] categorizes hybrid analysis into two types: Process based hybrid analysis, starting with process analysis of product production but compromise the total energy intensities derived from IO analysis, which can obviate the incomplete inherent with process analysis and Input-output based hybrid analysis, starting with the extraction of direct energy pathways from IO table and insert process analysis without unwanted data, which can improve the completeness and reliability of embodied energy analysis. The hybrid methods maintain the accuracy of process analysis within the complete system boundary identified by input-output data [19, 25]. It uses specific process data as many as possible and fill the system gaps with input–output data in order to assess the entirely of the supply chain of a product [17]. Treloar and Crawford developed hybrid energy coefficients to simplify the hybrid LCA of embodied energy by combining the available process data for individual materials with national average input–output data [26], therefore, the embodied energy is calculated by multiplying the quantity of each material in the building by this hybrid embodied energy coefficient.

However, the hybrid method also has the weaknesses of both the process based and I-O methods. As the hybrid method is aimed at achieving the most accuracy of estimation result, the cost of the hybrid method can be even higher than the process and the I-O methods, and the process is much more complicated than the other two. What is more, the quality of the hybrid method also depends on the availability and quality of data in both the process method and the I-O table[17].

3.2 Comparison of methodologies

The Process based LCA depends highly on the LCI database, and a perfect database should contain data of building materials, building services, energy supply, transport, and waste management service, etc. It is severely time consuming and labour intensive to construct a LCA database coving the complete system boundary. The Input-output LCA also faces the similar situation; the availability of region or national IO tables highly depends on the publications of government. Not all the country governments publish the IO table, and the comprehensive level of the IO table in each country is also different. For example, in the U.S. I-O table, the number of industrial sectors reaches nearly 700, thus suitable for a detailed analysis. [22], but the number of Japanese I-O table is approximately 400 [27, 28]. For other countries such as Thailand, the I-O table only has 100 sectors [29, 30]; and the number of Australia is around 200[11, 24]; although it is still effective in calculating intensities, but the assessment result will not be as accurate as that of America.

A comprehensive comparison of the three methodologies is shown as Table 2[15-17, 22, 31]:

Table 2: Comparison of the three LCA methodologies

Methodology	**Process based LCA**	**I-O LCA**	**Hybrid LCA**
Guideline/standard	ISO 14040/ISO 14044 UNEP EN 15978 SETAC	UNEP	N/A
Data source	Company/Manufacture data; Industrial data; Public institution data; Energy company data; Scientific publications	Government published IO table; National statistics about production, trade, investment, energy consumption;	Process LCA data; IO LCA data
Database-Country	ICE-Europe U.S. LCI Athena LCI-Canada Ecoinvent-Europe Gabi database-global CLCD-China ELCD-Europe	CMU EIO -US 3EID-Japan E3IOT-Europe	N/A
Tool/Software	Simapro Gabi eBalance BEES-construction industry, etc.	EIO-LCA	N/A
Advantage	Detailed analysis of specific processes; Product specific; Identify process improvements Tools and software available	Boundary is defined as the entire economy; Microscopic analysis; Data is free and open to public	Advantages of the two
Disadvantage	Subjective define of system boundary; Truncation error; Lack of comprehensive data; Time and cost intensive; Database is proprietary	Aggregation error; Difficult to identify improvements; Lack of comprehensive data; Time and cost intensive	Disadvantage of the two; more time and cost intensive.

Additionally, although many database and tools have been developed to support process based LCA, which highly make it more convenient to evaluators, one point must be noted that the lifecycle boundary of the database mentioned in Table 2 are all cradle to gate. This means when evaluating the embodied energy of building, the available tools could only facilitate evaluator to conduct the assessment within the material relevance, if the objective is to expand the lifecycle boundary, the evaluator need to find out the related data and information on his own effort.

3.3 Application of LCA in assessment of building embodied energy

Table3: Summary of reviewed papers in applying LCA

Year	Author	Location	Building type	Methodology
2005	Guggemos A[32]	USA	Commercial	Process analysis with Economic input-output data
2008	Aurora L [33]	USA	Residential	Input-output based hybrid
2010	Melissa M [34]	USA	Commercial	Process based hybrid
2006	Norman J [35]	Canada	Residential	Economic Input-output
2012	KV Ooteghem [36]	Canda	Commercial	Process analysis with published database
2011	J. Monahan [37]	UK	Residential	Process analysis with Simapro database
2008	JN Hacker [38]	UK	Residential	Process analysis with published data
2010	Gustavsson [39]	Sweden	Residential	Process analysis with published data
2007	S. Citherlet [40]	Switzerland	Residential	Process analysis with ESU database
2009	G.Verbeeck [41]	Belgium	Residential	Process analysis with Ecoinvent database
2000	Treloar [11]	Australia	Residential	Input-out based hybrid
2000	Roger Fay [42]	Australia	Residential	Process based hybrid
2002	Lenzen M. [43]	Australia	Residential	Input-out based hybrid
2006	Langston YL [44]	Australia	Residential	Input-output based hybrid
2015	EC Mpakati-Gama[45]	Malawi	Residential	Process analysis with published data
2002	B.V. Reddy[46]	India	Residential	Process analysis
2007	Oyeshola F.K[47]	Thailand	Commercial	Process based hybrid
2015	TJ Wen [48]	Malaysia	Residential	Process based hybrid with Gabi database
1995	Michiya Suzuki[27]	Japan	Residential	Economic Input-output analysis
1998	Michiya Suzuki[28]	Japan	Commercial	Economic Input-output analysis
2000	T.Y.Chen[49]	Hong Kong	Residential	Process analysis, available data from publications
2007	C.K.Chau[50]	Hong Kong	Commercial	Process analysis, global LCA database
2010	Hui Yan[51]	Hong Kong	Commercial	Process based hybrid, available data from publications

2013	XiaoLing Zhang[18]	Hong Kong	Commercial	Process based hybrid, available data from publications
2012	Yuan Chang [52]	China	Commercial	Process based hybrid, Input-output table and published data
2013	M.Y.Han[53]	China	Commercial	Process based hybrid, Input-output table and published data
2010	Yuan Chang[54]	China	Construction industry	Economic Input-output analysis, data from government publications

The sample of the literature reviewed tells that the most decisive factor in the selection of methodology to investigate the building embodied energy is the availability of life cycle inventory database and the national economic Input-output table. Input-output analysis is more likely to be adopted in the areas where the economic input-output table are available and comprehensive, such as USA, Japan, and Australia. The Green Design Institute of Carnegie Mellon University developed EIO-LCA model on the basic of the 519 sectors IO Table of the US economy; which facilitate the researchers to conduct input-out analysis, and one case in Canada also applied US EIO table to evaluate one Canadian residential building, by the assumption that the construction materials used in Canada is identical with that used in America. Australian researchers developed energy-based I-O model and I-O based hybrid model of the economy on the basis of national input-output table produced by Australian Bureau of Statistics (ABS).

For European researchers, process analysis LCA is more dominant than IO analysis that is because the lifecycle inventory database in Europe is localized and comprehensive such as ESU, Ecoinvent, etc. The participation of industry contributes a lot in developing the LCI database and LCA software like Simapro, Gabi to facilitate the evaluation process. And in Asian countries, the process-based hybrid LCA is welcomed in many studies. This methodology starts with the process analysis and employs some energy intensity data derived from I-O analysis to fill the data gap in LCI database, which help the study to make up the shortcoming of the local data and also be specific to building level.

Additionally, when C.K. Chau wanted to evaluate the environmental impacts of a building in Hong Kong, he pointed out that the European LCI database could not be used in Hong Kong directly, so he developed a method to adjust the European LCI data to meet the Hong Kong conditions, therefore the LCA results would reflect the local construction practice. According to C.K Chau, the localization of LCI data involves the following adjustment[50]:

1) Replacement of the fuel mix for electricity generation assumed in database by those whose countries in which the building materials are manufactured.

2) Inclusion of the impacts incurred by transportation of the materials or components from their originations to Hong Kong.

3) Inclusion of the impacts incurred by the local construction activities, such as the energy consumption in each construction processes.

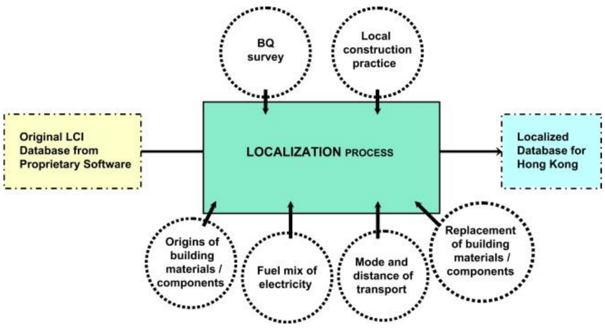

Fig.3 Illustration of information required for localization process [50]

4. Discussion

The comparison and past studies show that each of the three methodologies (Process, I-O, Hybrid) has the advantage, limitation and applicability of its own. If the purpose is to evaluate the embodied energy of one specific building, for example, when designing a green building, the designer need to know the embodied energy of the building materials and components and check out whether there is space to improve; or the building is participating a green building assessment system like LEED, HK-BEAM or BREEAM, etc., the process based LCA will be the choice. However, if the purpose is to get the average embodied energy consumption of industry, sector and national level, for example, to formulate industry energy saving policies, or to plan the energy consumption benchmark of industry level, Input-output based LCA could be the choice.

Additionally, when applying these methodologies in embodied energy evaluation, there are some considerations should be taken notice. The first consideration is all the three methodologies have geographical limitation. The material production technology, quality, manufacture process, usage of energy mix, economy development, transportation distance, etc., all these factors are different in different countries, and keep dynamically changing as the development of society, technology, and international situation. Therefore, even the localized lifecycle inventory database could not promise that the data reflect the current practice. As many previous studies mentioned above adopted the published material intensity data, the authors should know that the adoption of those published data is assumed that the materials to be evaluated is identical with the ones to be referred.

The second consideration is that the difference between primary energy and delivered energy in evaluation. Usually, the assessment of embodied energy is in terms of primary energy, which means the energy form from the renewable and non-renewable natural resources like coal, solar, natural gas, etc. In LCI database, the energy intensity of material is in the unit of primary energy. However, if the defined system boundary includes the construction process, in some cases, the electricity consumed for construction equipment, and temporary buildings on site are also calculated, however, electricity consumed onsite is classified by term "delivered energy", which is a misleading point.

For the last point, there have not been any regulations to demand the academy and industry to take which methodology for the quantification of embodied energy. No matter the methodology chosen, the system boundary defined, or the adoption of LCI database or open published data, all these issues depend on the evaluators' objectives, understandings, and preferences. The uncertainty and incompleteness almost exist in each step of the three methodology processes. As a result, it is hardly to compare the accuracy of evaluation results by the three methodologies.

5. Summary

In a summary, getting a clear evaluation of building embodied energy is significant in reducing building energy consumption through its whole lifecycle. The three dominant evaluation methodologies all have the advantages, disadvantages, and feasibilities of their own. Process based LCA is suitable for the assessment of component or building level and is supported by many LCI database and LCA software. Input-output LCA can be applied to evaluate the average embodied energy consumption of sectoral, reginal, or even national level. And the hybrid LCA shares the both merits and defects of the former two methods. The evaluator needs to choose the most appropriate method according to the evaluation objective (building level or industry, sector level), evaluation boundary (cradle to gate, site or end of life) and available resource (budget to purchase proprietary database, labour force in data collection, etc.) What is more, the localization of foreign database, the development of society, economy, manufacture technology, transportation mode, the dynamic changing international situations, and fluctuation of commodity prices, international trade tariff, etc. so many factors existing to cause uncertainty and inaccuracy, therefore, although it is hardly to judge the veracity of evaluation result, the evaluators need to pay attention and take some measures such as the adjustment factor, to achieve a more reasonable and acceptable result.

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Designing city installations for socially and environmentally responsible behavior

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Abstract

As a result of global climate change, financial crisis, and the public perception of massive overconsumption, designers are increasingly motivated “to do good for society”. In this paper, city installations are considered as good opportunities to connect with public and raise their awareness to sustainability. This is while responsible design and sustainability rarely are the focal points of designing street furniture. The conventional goal of sustainable design initially was to design products that require the least energy to be produced and used and that could be recycled. Currently, the idea of sustainable design is growing to have some type of a higher calling, which may be social responsibility and a public design. This becomes more important in developing countries like Iran, which sustainable issues are still not a public concern.

This paper presents a design case study at Art university of Isfahan, Iran, which explores how designers and design educators can set their own holistic approach to sustainability in new product development, place social awareness, responsibility and behavior in perspective. The experiment consists of practices for designing city installations which are not neutral but a deliberate means to promote different levels of sustainability. The proposed design interventions through the conducted experiment are presented and analyzed with their level of success for implementing different levels of sustainable design from eco-design, to raise public awareness of sustainability, sensate or educate people, and cause sustainable behavior through one of the design strategies of coercive, decisive, persuasive, or seductive.

Keywords: city installations, responsible design, environmentally aware, sustainable behavior;

1. Introduction

Street furniture are installed in different locations of a city, are daily used by a large public, and have the closest contact and most dynamic interaction with people and the environment. Therefore, they have a great responsibility to benefit the urban and society development. According to Rehan, "sustainability in street furniture is one of the most important strategies for sustainable urban design" [1]. Although comparatively small in scale, street furniture is an element that can play an essential role in developing the quality of urban spaces with added value of representing city identity [2]. Gehl [3] asserts that street furniture also can offer positive social influences on users (Wai, Siu, Sing, & Wong, 2015). Despite with all the possible benefits given, early observation has found that there is still a lack of understanding towards sustainable design of street furniture. As revealed by Tazilan et al. [4] over the past decades, sustainable criteria have been lacking or have not been applied to most of the current street furniture designs. This encourage us to focus on street furniture and city installations for adopting the concept of sustainability through the local cities.

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2. Design for sustainability in city installations

The traditional approach to environmental management has evolved from pollution control, the end-of-pipe approach, to preventive or cleaner production strategies. The fundamental eco-design strategies are:

- Design for Manufacturability
- Design for Energy Efficiency
- Design for Dematerialization
- Design for Modularity
- Design for Longevity
- Design for Disassembly
- Design for Packaging
- Design for Logistics
- Design for Multi-functionality
- Design for Serviceability
- Design for use of recycled materials
- Design for Recycling
- Design for healthy materials

Recently, it has become clear that such interventions must be more radical and go beyond the redesigning of existing products in order to catalyze a transition towards a sustainable society. Design for Sustainability (DfS) goes beyond these eco-design strategies. DfS integrates social, economic, environmental and institutional aspects and offers opportunities to get involved one's own identity beyond consuming standardized mass products[5]. DfS suggests that a typical win-win situation is not only the eco-efficiency of production, but also the eco-efficiency of consumption and sustainable consumption[5]. A product is efficient if the abovementioned eco-design strategies are applied in its design process, and if the use efficiency of this product can also be extremely low (most of the time the product is not used). Hence, detecting possibilities for improvement of socio-cultural rather than technical, like improving the use intensity can lead to better results in eco-design and is a step forward to design for sustainability. Choosing bicycle instead of car in the Netherland is one the best successful examples of sustainable consumption instead of focusing on making that product eco efficient. The need for sustainable behavior introduces a relatively new issue into the global debate on sustainable development. Sustainable behavior questions, not only products and services but also the way that needs and wants are defined and fulfilled [6].This means that designers need to be made aware of their new responsibilities and to become competent to make specific contributions in the transition towards a sustainable society.

Accordingly, this paper aims to explore the possibilities of promoting sustainable behaviors through the current societies by developing new ideas for city installations. The research discusses the sustainability issue of city installations design and seeks to implement street furniture which drives the community towards a deep sustainability. While the common examples of street furniture are functionally designed ignoring the important roles that they can play in the communal living, some emerging trends are applied in the literature in order to increase the benefits of street furniture for the society, the city and the environment; the examples are as follows:

- Multifunctional ICT devices like a bus station, which acts as a cloud device and includes screens that display real-time information about bus movements and touch-screens that provide access to interactive maps, local news, tourist information as well as a USB charging port for mobile devices and advertising.
- Responsive Street Furniture, which adapts to the needs of individuals. The adaptions include brighter street lighting, audio information, extra places to use and more time to cross the road.
- Sustainable Technology like Energy Solar LED Street Lamps or roads with renewable energy use.
- Modular Street Furniture
- Flexible or Pop-Up (Hydraulic Power Units) Furniture.[7]

This paper explores the possibilities in which street furniture can influence on society and raise public awareness of sustainability or even lead to some behavioral changes and promote sustainable behavior.

2.1. Design for raising public awareness of sustainability

Since street furniture has the closest contact and most dynamic interaction with people and the urban environment [8], it can be applied for giving messages to the public. There are scattered examples of city installations in the literature that aim to catch public attention to the environmental issues. The floating Plastic island installation[9]in Portugal is

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one the examples which is made of 5000 recycled plastic bottles. It replicates, at a smaller scale, the so-called "eighth continent" made of plastic and garbage which is alarmingly taking over great areas of the Pacific. Rain Interactive installation[9]in London is another example which highlights the vital need of water and how abhorrent it is to privatize it and trade it for the profit of just a few. The labyrinth of plastic waste[9]in Poland, the Rising Moon installation[10] at Victoria Park in Hong Kong and the glowing labyrinth of plastic waste[9]which placed around the plaza's statue of King Philip III in Madrid are other examples that demonstrate, in a poetic manner, the amount of plastic waste that is consumed daily, in addition to focusing attention on the big business of bottling water. The Tetris-shaped street furniture[11] located within a city park in Córdoba, Argentina, is another remarkable example that is designed to teach passerby about sustainability issues. These unique seats and tables showcase recyclable materials like plastic bottles, cans, and paper, and feature easy-to-understand eco-facts written on the surface of each piece. Park(ing) Day [12] is one the successful events to call attention to a lack of public green spaces and high car usage. It was started by Rebar, a San Francisco art and design studio and has become a global movement that takes place on the third Friday of each September. In a Park(ing) Day, metered parking places are changed to a public park and recreational space.
While, such types of design interventions can sensate the public to the sustainability, acquiring a deep influence and a certain changing behavior are not expected. However, they are considered as an initial step toward shaping a sustainable society.

2.2. Design for promoting sustainable behavior

A product is not a neutral intermediary, but a mediator that actively mediates the relation between a user and his or her environment. Tromp.et. al. [13] used the example of the microwave to show that design would influence behavior patterns even implicitly and unintentionally. Utilizing microwave make families join together for fewer dinners than they did before because the microwave oven has made it so easy to quickly heat up an individual meal. This example shows that products can mediate certain behavior even without determining it. Accordingly city installations are sometime deliberately designed to change behavior in order to prevent an undesired behavior or to encourage a desired behavior. Tromp.et. al. introduces four different types of influence on user experiences, namely, coercive, decisive, persuasive, and seductive[13].
Coercive refers to a definite prevention of an undesired behavior. Speed bump, speed limit camera are the examples of a coercive intervention to stop risky driving behavior by making a punishment for the undesired behavior. Making a perceivable barrier for undesired behavior (pain) or making unacceptable user behavior overt (shame) are also considered as the examples of coercive strategy for changing behavior. Decisive strategy is making the desired behavior a necessary activity to perform. Customize receptacles with different openings for trash, recyclable objects (e.g. bottles and papers) is an example of a decisive intervention.
While coercive and decisive are strong types of design interventions and lead to a definite change of behavior, their effects seems to be temporary and not deep on people. Meaning that people would follow their own behavioral patterns in case of removing the barriers and interventions. Fogg introduced the term of persuasive design that aims to alter attitudes or behaviors of users through persuasion and social influence, but not though coercion [14]. Poor little fish basin[15] designed by designer Yan Lu is an example of persuasive design, which is an emotional feedback device for saving water. Social Stairs, the Piano Staircase [16] is another persuasive design which encouraged people to take the stairs in favor of the elevator by triggering new motivations. Their study on the resulted behavioral changes revealed a high level of long-term social engagement. Seductive is another design intervention which can lead to a changed behavior unconsciously by triggering human tendencies for automatic behavioral responses. Woonerfs the "living streets" are the best examples of this design intervention. The concept of the woonerf was developed in the late 1960s in the city of Delft, Netherlands[17]. Residents of a neighborhood were upset with cut-through traffic speeding through their neighborhood, making it unsafe. They believe eye contact and human interaction are more effective means to achieve and maintain attractive and safe areas than signs and rules. Hence, they initiated woonref, in which the street is shared among pedestrians, bicyclists, and motor vehicles. But pedestrians have priority over cars. The street is designed without a clear division between pedestrian and auto space (i.e., no continuous curb), so motorists automatically slow down and travel with caution[17].

3. Conducting the experiment

3.1. Designing of city installations for sustainability

Although design has proven to be an influential factor in behavior, only for a few years have design researchers tried to gain adequate knowledge that would allow designers to deliberately and effectively affect behavior. The ability to

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conceive and practice a type of design that acts as a catalyst for something beyond the immediate product and holds the responsibility in positively influencing entails a shift in the definition of professional profiles and education. According to Deniz 2016, designers generally assume that their area of responsibility is limited to function and appearance and rarely spread through the effects of their designs on people and environment no miner what their scale is [18]. Hence, design practices increasingly need to go beyond styling trends, consider environmental threats, recognize social and behavioral gaps and design to fill the gaps.
At Art university of Isfahan (AUI), an experiment was conducted in order to explore the promises and challenges of designing for deep sustainability within the context of a developing country like Iran. The experiment explored how designers can set their own holistic approach to sustainability in new product development, place social awareness, responsibility and behavior in perspective and provide an inspirational practices for student designers. Accordingly, the experiment was conducted at Industrial Design Group of AUI under the template of a course named ‘Design 5’, an exemplary for a regular street furniture and city installation design course. The course has been offered for many years in a broad spectrum of disciplines as aesthetics, ergonomics, manufacturability, market considerations, but not sustainability. Through this experiment, an increased emphasis on environmental issues and sustainability was practiced. The main objective of the experiment was to develop design interventions which affect and guide the society toward sustainability. Specifically students were asked to design a city installation or street furniture which is not neutral but improves the sustainability within their context. Accordingly the developed design interventions need to apply the following strategies:

- Eco-design (e.g. Minimizing the environmental impact, using recycled and recyclable materials, dematerialization, naturalization, modularity, extending product lifecycle)
- Raise public awareness of sustainability
- Educate and sensate public on sustainability
- Promote sustainable behavior with any of the design strategies for changing behavior, namely, coercive, decisive, persuasive, and seductive.

Figure 1 presents the spectrum from a not sustainable design to eco-design and a socially responsible design. The design students are encouraged to move toward the end of this spectrum for establishing a deeper level of sustainability in the society.

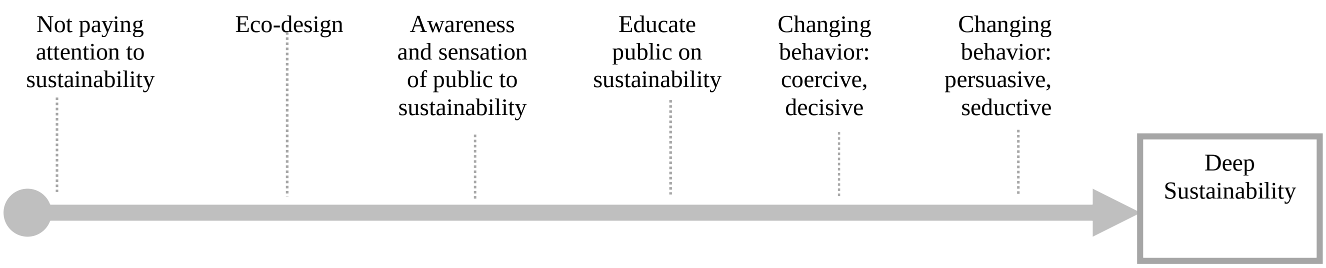

Fig. 1. Different levels of Design for Sustainability

3.2. The developed design interventions

There was not one or more predefined subject in this experiment. Students needed to research on the existing environmental and social problem through the specified context of the city and defined their own design intervention to address that problem. Hence, recognition and treatment of pain using the power of design was the leading directions of the projects. In the following, the developed design interventions by the students are discussed.

Flexible bus stop[1]
Paying attention to the flexibility in designing of street furniture like bus stops is the starting point of this project. Accordingly the bus stops can be more durable and better adapt to different needs of people in different times, different functions and different locations. The project follows eco-friendly strategies in defining the materials, joints, modularity and etc. However it does not go deeper for promoting sustainability within the society (see Table 1, a).

[1] Designed by: AUI industrial design student,Zhara Mehralaian

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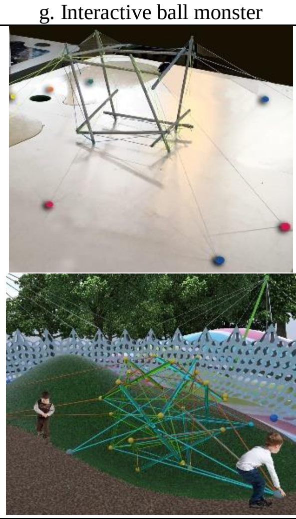
Table1 The developed design interventions for sustainability during the experiment

a. Flexible bus stop	b. Parklet	c. Recycling Café
		
d. Eco-aware drinking fountain	e. Droplet urban drinking fountain	f. Natural Urban drinking fountain
		
g. Interactive ball monster	h. Ecological pedestrian rout	i. Educational recycling bin
		

Parklet[2]
Chaos in pedestrian routs, mixing the behavioral territories, lack of seating and common areas in the crowded parts of the city and lack of social interactions bring out the idea of Parklets (public spaces that replace street parking). Parklets are pavement-reuse initiative and enhance green spaces of the cities. With temporary and lightweight structures, Parklets can be constructed to improve the quality of environment through the cities. In some examples, the Parklets are set up in the parking areas giving a strong message to the public for less usage of personal cars (see Table 1, b).

Recycling Café[3]
With regard to the little efforts made for public awareness on environmental issues in developing countries like Iran, the project proposes the idea of a recycling café which is composed of recycled materials such as plastics. According to the Iranian Department of Environment[19], the usage of plastic in Iran is 3 times larger than the universal average usage. The project gives people the opportunity to gain information on their overuse habits, get experiences in recycling processes, make their own chairs out of recycled materials, and spend time in this café (see Table 1, c).

Eco-aware urban drinking fountain[4]
The project proposes an urban drinking fountain with three different types of eco-friendly materials (e.g. terracotta, mosaic, bamboo, straw mat and rope) in different contexts, like, historical, natural and childish settings. Wasted water from the fountain irrigates the plants underneath the fountain and the used symbols applied in the fountain sensate the public to the water consumption (e.g. penguins, ducks and other animals who live in water are used as water tab to aware kids on the importance of water for the life of animals). Such kinds of urban drinking fountains can be considered as an eco-friendly design which tries to aware and sensate the public to environmental issues (see Table 1, d).

Droplet urban drinking fountain[5]
With attention to the extreme lack of water in different cities of Iran, the project aims to aware the public to this fact. Hence, the designed urban drinking fountain with a different appearance and a droplet function tries to make people think about this serious environmental problem. The whole structure of the fountain simulates a raining state, but it gives water to the consumers in a dropping manner. Hence, it gives a message to the public on the overuse water consumption and can sensate consumers on this issue (see Table 1, e).

Natural Urban drinking fountain[6]
The project presents an urban drinking fountain which passing the water through a piece of natural stone with a small carving on it to value the water and to promote water conservation. The idea stems from the traditional Persian drinking fountains which proposed a kind of holy water to the consumers. The designed fountains are gathered around a handmade wood stick tree reminding a dry tree which can be Irrigated by the wasted water of the fountain. In comparison with the conventional urban drinking fountains composed of metal or other modern materials, this natural drinking fountain can better communicate with public. It catches the public attention to the purity and importance of water for not being wasted (see Table 1, f).

Interactive playful ball[7]
The project aims to address the growing concern over the increasing isolation and loss of interactions among the new generations who are drowned in digital lifestyles. While most of the playgrounds are limited to individual gaming or just gathering children around, the interactive playful ball promotes children to collaborate and interact with each other in order to reach a shared aim which is moving and changing the shape of the ball. Hence, this design intervention can be considered as seductive design which tries to promote a positive behavior in children unconsciously (see Table 1,g).

Ecological pedestrian rout[8]
Starting from the problem of chaos in the large cities of Iran caused by not following the routs which are designed for pedestrians, bicycles, motorcycles and cars, the project presents a parametric rout out of recycled materials. The rout is designed for the most crowded urban node of the city and tries to influences on people`s movement by guiding them to the correct directions. The designed structure also offers multiple activities such urban gardening, voluntary environmental and social activities. Accordingly, it can be categorized as a persuasive and seductive design intervention (see Table 1, h).

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[2] Original idea refers to Andres Power, 2008 [20], and the project is developed by AUI industrial design student, Javid Namdar

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Educational recycling bin[9]

The project presents a recycling bin combined with some lighted birds and their nests. By throwing wastes (e.g. paper, plastic, and trash) to the correct bin the related colored bird light up. Accordingly children are motivated to feed the birds with more wastes while learning how to separate the recycling material. Such a kind of design intervention can sensate and educate people on environmental issues and persuade them to do good things for the environment. Children can also interact with the real birds through this urban furniture. Children can feed the toy birds by bread, shake their wings to chop the bread and make the food for the real birds living in the nests on top of the recycling bin (see Table 1, i).

3.3. Evaluating the design interventions

Evaluating the design interventions shows that the experiment leads to expand design context in thinking and practicing something beneficial for the society and set new aspirations, change perceptions of students by making use of the diversity of ”value-added’ criteria’s to design process. However, the developed design interventions are not equally contributed with the social community to promote sustainability and enhance socially responsible behavior among the public. Figure 2 represents a categorization of the design interventions for establishing sustainability. Moving from center to the outside of the diagram indicates a more influential and longer-term design intervention.

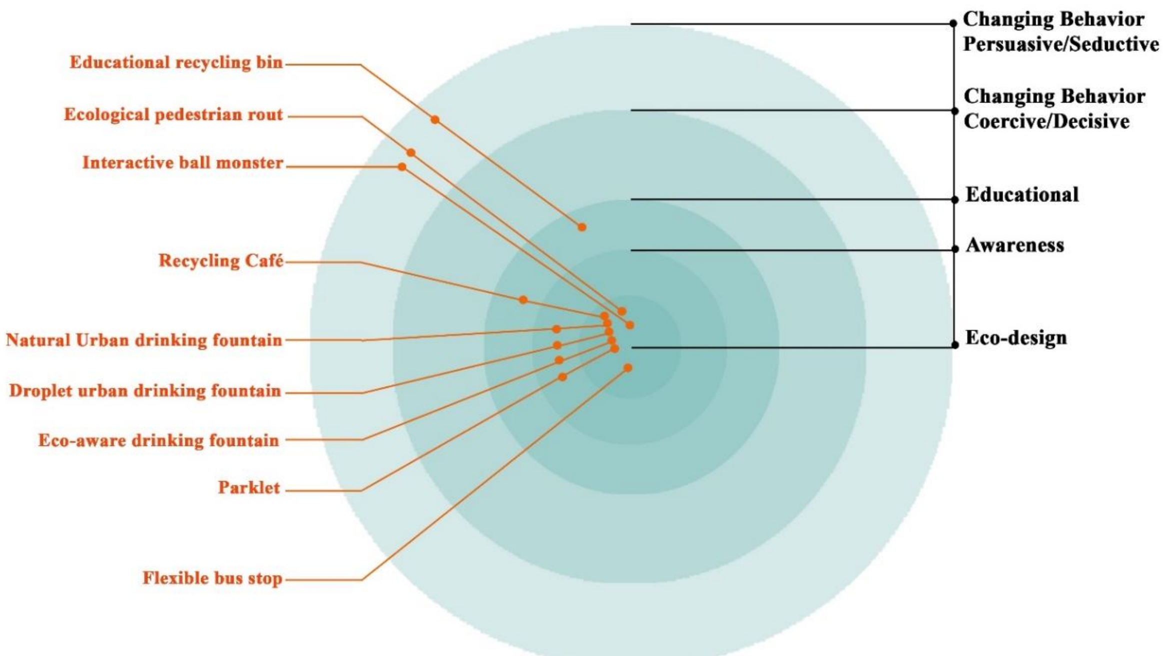

Fig. 2. Categorizing the design interventions for establishing sustainability

4. Conclusion

The paper proposed to deepen the design of city installations from functionally designed and eco-design to a more influential design for sustainability. While the developed design interventions of the conducted experiment tried to have the least environmental effects, their focal point was to have a multi-layered design; meaning that they aimed to address the existing needs of a city life in an expressive manner. For instance, an urban bin should be rubbish removal in a city and correctly contains wastes, but it can also play more role in the city by engaging children in an interesting game, teaching them how to separate trash for recycling and encouraging them to keep the streets and the environment clean. An urban drinking water should satisfy the thirst of people, but it also can create different drinking experiences and simultaneously give strong messages on the value of water and the importance of water conservation. By such a kind of design interventions, street furniture are no longer inactive objects in the cities but be alive and communicative to people. Outcomes of the study reveals that city installations can effectively act as a facilitator to sensate people on

[9] Designed by: AUI industrial design student,Zahra Ghiasi

serious social and environmental problems, make them thinking on these issues, even influence on people behavior by promoting socially responsible behavior and finally establish sustainable cities.

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Design for Sustainability in education

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Abstract

While the potential for designers to affect positive change is significant and widely acknowledged, this has remained largely untapped both within industry and education. Although some new educational curricula with environmental emphasis have begun to be developed and implemented. But this is barely a beginning and the new generation of designers still needs to be more educated in sustainability. Current design education have been rarely recognized as a relevant factor in the sustainability discourse. Furthermore, the educational practices are mostly related to eco-design strategies (e.g. energy efficiency, dematerialization, longevity, use of recycled materials, recycling). But Design for Sustainability (DfS) goes beyond the eco-design. DfS integrates social, economic, environmental and institutional aspects. Hence, it is necessary to expand the scope of design education and practice beyond style, fashion or limited trends of environmental concerns to include behavioral, social, institutional issues.
Accordingly, an educational experiment is undertaken by the industrial design students of the Art University of Isfahan, Iran which provides a more coherent framework for sustainable design education. Students have the responsibility to not only include eco-design strategies but also establish Design for Sustainability which promote socially responsible behavior among people. The paper contributes to the knowledge and experience on how integration of sustainability issues in regular product design courses can be accomplished the design activity in order to positively and effectively contribute to the radical change required by the transition towards a sustainable society.

Keywords: city installations, design for sustainability, green design, public awareness, sustainable user behavior;

1. Introduction

Since the 19th century, mass production of objects transformed design from an art into a stakeholder co-shaping the future of societies. This mass production has generated negative social, environmental or institutional aspects, such as, global warming, resource depletion, solid waste, water pollution, air pollution, land degradation. Joachim, in his research entitled DEEDS named ‘mess production’ by mass production [1]. As Hawken argued, the industrial system is destroying the planet and only industry leaders are powerful enough to stop it [2]. Hence, the entire production and consumption system in the coming decades will require a radical reorientation as we move towards a sustainable society [3].

The traditional approach to environmental management has evolved from pollution control, the end-of-pipe approach, to preventive or cleaner production strategies. Recently, it has become clear that such interventions must be more radical and go beyond the redesigning of existing products in order to catalyze a transition towards a sustainable society. The need for sustainable behavior introduces a relatively new issue into the global debate on sustainable development. Sustainable behavior questions, not only products and services but also the way that needs and wants are

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defined and fulfilled [3].This means that designers need to be made aware of their new responsibilities and to become competent to make specific contributions in the transition towards a sustainable society.

Unfortunately, so far sustainability plays a minor role in design education and practice. Design education and profession have been rarely recognized as a relevant factor in the sustainability discourse [1]. Although in the last two decades, this situation has changed. Environmental issues have now penetrated society, education and systems of production. In particular new educational curricula (with an overt environmental emphasis) for designers have begun to be developed and implemented. But this is barely a beginning. A whole new generation of designers still needs to be educated and employed [3]. Furthermore, the educational practices are mostly related to eco-design strategies (e.g. energy efficiency, dematerialization, longevity, use of recycled materials, recycling and etc.). But Design for Sustainability (DfS) goes beyond Design for the Environment or eco-design. DfS integrates social, economic, environmental and institutional aspects and offers opportunities to get involved one's own identity beyond consuming standardized mass products [1]. Hence, it is necessary to expand the scope of design education and practice beyond style, fashion, economic issues and limited trends of environmental concerns to include behavioral, social, institutional issues.

Accordingly, this paper aims to provide one step forward in Design for Environment and uses the power of design as a deliberate means to change behavior of people. To this aim, an educational experiment is undertaken by the industrial design students of the Art University of Isfahan which provides a more coherent framework for sustainable design education. The experiment consists of practices for designing city installations which facilities and promotes sustainability within the city. Students have the responsibility to not only include eco-design strategies but also establish a design for socially responsible behavior.

Consequently, the paper is outlined as follows: after defining the scopes of Design for Sustainability in current societies in which environmental issues were not pre-eminent, responsibilities of designer as catalysts of society in raising public awareness are largely discussed. Following, the need for focusing on socially and environmentally responsible design in education and the case study experiment at Art University of Isfahan are outlined. Finally, we evaluate the consequences of involving DfS educational program in design courses by categorizing and comparing the developed concepts of students with the outlined aims of deep DfS.

2. Design for Sustainability beyond Design for Environment

Design is an environmental focal point since design decisions have huge impacts on the environment. Considering environmental issues, designer's responsibilities become more difficult and more important than before. Designers have crucial responsibilities to create environmental friendly products and solutions for the earth. In 1971, Victor Papanek in his book Design for Real World define Design for Environment (DfE) as a design practice which dedicate itself to nature`s principle of least effort[4]. That means consuming less, using things longer, recycling materials, and not wasting. DfE is a method to minimize or eliminate environmental impacts of a product over its life cycle. Effective DFE practice maintains or improves product quality and cost while reducing environmental impacts. Reviewing the literature shows fundamentals of design for environment can be categorized in the eco-design strategies reported in Table 1.

Increasingly more companies try to apply the above mentioned strategies in order to undergo the Cardle to Cardle (C2C) criteria's in green design. The Interface Corporation (carpeting company) is one the first and most popular companies that progressed on industrial ecology by applying multiple eco-design strategies like design for modularity (producing modular commercial floorcovering), design for serviceability (moving from selling carpets to providing a carpeting service), energy efficiency, use of recycled materials and etc. Herman Miller is a furniture company that launches their new chairs with environmentally friendly and non-toxic materials, recycled materials, easy to disassemble, high levels of recyclability after usage (both up-cycle and down-cycle), 100% green power during production line (no air or water emissions released in production), returnable and recyclable packaging. The emphasis of new Herman Miller chairs is on eliminating as many materials as possible from the construction. This "eco-dematerialization" strategy results the fewer parts and less material, the lower cost, the lighter carbon footprint and less shipping costs. Steelcase is another furniture company which applied multiple eco-design strategies, mainly, easy disassembly, using fewer parts, eliminating adhesive, eliminate the used staples and recycling. Not only Dematerialization but also Rematerialization is another eco-design strategy which is followed by many companies. Freitag bags uses truck tarps, inner tubes and seat belts to make new bags. Patagonia Clothing uses post-consumer recycled materials in their products. Dunlop Wellington boots takes back used Wellingtons from customers. Old boots are re-ground and re-manufactured into new boots. Adidas uses ocean plastic and illegal deep-sea gillnets to make new shoes. Pentatonic created a range of furniture and products from food, electrical, plastic and textile waste, smartphones, cans and cigarette butts. Design for longevity is another eco-design strategy which is followed by companies like Stokke which applies flexibility and multi-functionality as the main idea of their product and produces furniture like Tripp Trapp Chair and Daybed that grow with the child.

Table 1. eco-design strategies

DfM Design for Manufacturability, Enabling pollution prevention during manufacturing Design for less material Design for fewer different materials Design for safer materials and processes	**DfL Design for Longevity,** Provide life time period of usage Flexibility Design for modularity Design for serviceability Design parts/products so that components contain materials with reuse potential in other industries.
DfEE Design for Energy Efficiency, Reduced energy demand during use Use renewable energy Zero Emission Carbon Neutrality	**DfMo Design for Modularity,** To ease upgrading, To delay replacement, To ease serviceability To ease later disassembly For Longer life,
DfD Design for Dematerialization, Use less virgin material Design products with less mass Reduce packaging Modify manufacturing processes to reduce by-products Maximize use of recycled materials	**DfDi Design for Disassembly,** To promote re-use of components, For quicker and cheaper disassembly, For more complete disassembly For dismantling by simple tools
DfP Design for Packaging, Minimize packaging, Rethink selling method or rethink ways to reach the customer	**DfL Design for Logistics,** Use of local materials, Less transportation or arrange outsourcing to minimize transportation
DfS Design for Serviceability, For ease of repairs, Longer life, For recapture of used/broken parts.	**DfMu Design for Multifunctionality** Use one pro duct for different purposes Design for flexibility to enable changes for different functions, users, times and etc.
DfRM Design for use of recycled materials.	**DfHM Design for healthy materials**
DfR Design for Recycling, Labeling of parts, especially plastics for easier materials identification Efficient choice of materials (thermoplastics easier to recycle than thermosets) Modify manufacturing processes so that by-products can be recycled Design with less variety of materials Use of materials that can be locally recycled Design for greater materials recovery Design for safer disposal of non-recyclables Design for Economic Recycling, arrange for material reclamation, marketing incentives to promote recycling	

Accordingly, different levels of design for environment can be recognized by reviewing the existing efforts in applying the eco-design strategies. While some of the modifications are superficial, others try to modify the product (e.g. type, weight, material, packaging, service) or the procedure of making the product. A deeper levels of eco-design can be achieved by making changes to the entire product and trying to meet the function (service) in a different way. The changes from regular “snail” mail to email, film camera to digital camera, audiotape player to CD player and to iPod are examples of this deeper level of eco-design. However, as Arne Naess expressed [5], a “deep ecology” is not asking “How can we improve this product or activity?” but instead it should be “Why do we need this? Can we rather do without?”

Products (including services) are in between production and consumption (the ways they are used) [1]. Hence, a typical win-win situation is not only the eco-efficiency of production, but also the eco-efficiency of consumption and sustainable consumption. A product is efficient if the abovementioned eco-design strategies are applied in its design process, but the use efficiency of this product can also be extremely low if most of the time the product is not used. For example, there is simply little to be optimized in a kettle’s heating system, but if the amount of unnecessary water we repeatedly boil could be reduced, a substantial reduction in energy loss could be achieved. According to Lofthouse[6], study on users` behavior during the use of a kettle, users tend to fill the kettle fuller than required, turn the kettle on, walk off to do something, then come back 5 minutes later and reboil the kettle before using the hot water.

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Hence, detecting possibilities for improvement of socio-cultural rather than technical, like improving the use intensity can lead to better results in eco-design and is a step forward to design for sustainability. Choosing bicycle instead of car in the Netherland is one the best successful examples of questioning the need for a product and sustainable consumption instead of focusing on making that product eco efficient.
Design for Sustainability particularly aims to address the use efficiency, adding the qualitative component with social and institutional criteria[1]. Hence, DfS is understood to address not only product aspects but all dimensions of sustainability, looking at bigger systems and asking more fundamental questions about consumption and production. Unfortunately, so far, sustainability policies are based on preciously little insight to what it takes to change consumer behavior towards sustainable consumption.

3. Changing behavior by design

As discussed, re-thinking lifestyles and behavioral changes will lead to greater increases in sustainability compared with redesigning products. But how design can change behavior?
Lifestyles are shaped by context and habit, and changes require at least three conditions to be given:

1. The personal motivation and information,
2. The ability to change given the restrictions of the social context (acceptance, image, peer group identity etc.)
3. The opportunity, i.e. the availability of alternatives at competitive logics.

Design plays a significant role in regulating the three above mentioned conditions through ‘form-giving’, raising awareness, changing perceptions of value and integrating these elements [7]. A product is not a neutral intermediary, but a mediator that actively mediates the relation between a user and his or her environment. Tromp.et. al. [8] used the example of the microwave to show that design would influence behavior patterns even implicitly and unintentionally. Utilizing microwave make families join together for fewer dinners than they did before because the microwave oven has made it so easy to quickly heat up an individual meal. This example shows that products can mediate certain behavior even without determining it.
Products that are deliberately designed to change behavior are often based on the occurrence of undesired behavior. People eat unhealthily, people drive unsafely, people irritatingly hang around at specific places, people do not pay for their train tickets, and people do not care much about the environmental issues. Designers can intervene either by discouraging the problematic behavior or by encouraging other desired or accepted behavior that is incompatible with that undesired behavior and can thereby trigger different psychological processes. Tromp.et. al. introduces four different types of influence on user experiences, namely, coercive, decisive, persuasive, and seductive[8].
Coercive refers to a definite prevention of an undesired behavior. Speed bump, speed limit camera are considered as a coercive intervention to stop risky driving behavior by making a punishment for the undesired behavior. Making a perceivable barrier for undesired behavior (pain) or making unacceptable user behavior overt (shame) are also considered as the examples of coercive strategy for changing behavior. Decisive strategy is making the desired behavior a necessary activity to perform to make use of the product function. Customize receptacles with different openings for trash, recyclable objects (e.g. bottles and papers) is an example of decisive intervention.
While coercive and decisive are strong types of intervention and lead to a definite change of behavior, their effects seems to be temporary and not deep on people. Meaning that people would follow their own behavioral patterns in case of removing the barriers and interventions. Fogg introduced the term persuasive design that aims to alter attitudes or behaviors of the users through persuasion and social influence, but not though coercion [9]. Poor little fish basin designed by designer Yan Lu is an example of persuasive design, which is an emotional feedback device for saving water. Social Stairs, the Piano Staircase is another persuasive design which encouraged people to take the stairs at work in favor of the elevator by triggering new motivations. Their study on the resulted behavioral changes revealed a high level of long-term social engagement. Seductive is another design intervention which can lead to a changed behavior unconsciously by triggering human tendencies for automatic behavioral responses. Woonerfs the “living streets” are the best examples of this design intervention. The concept of the woonerf was developed in the late 1960s in the city of Delft, Netherlands. Residents of a neighbourhood were upset with cut-through traffic speeding through their neighbourhood, making it unsafe. They believe eye contact and human interaction are more effective means to achieve and maintain attractive and safe areas than signs and rules. Hence, they initiated woonref, in which the street is shared among pedestrians, bicyclists, and motor vehicles. But pedestrians have priority over cars. The street is designed without a clear division between pedestrian and auto space (i.e., no continuous curb), so motorists automatically slow down and travel with caution[10].

4. Socially and Environmentally Responsible Design in education

Although design has proven to be an influential factor in behavior, only for a few years have design researchers tried to gain adequate knowledge that would allow designers to deliberately and effectively affect behavior. The ability to conceive and practice a type of design that acts as a catalyst for something beyond the immediate product and holds the responsibility in positively influencing entails a shift in the definition of professional profiles and education. As Paolo Tombesi declared this is the difference between training and education: the former teaches the “what” and “how” of things, while the latter focuses on the “what” and “why” of actions [11]. The common design educational culture generally tends to encourage the expression of the ego and the aesthetic as well as functionality through formal design under the primacy of economic restrictions, whereas more emphasis should be placed for socially and environmentally responsible design. As a result of the common design educational culture, most of the design professionals educated without reference to the environmental impact of their design decisions and activities. In this case, many designers assume that their area of responsibility is limited to function and appearance and do not spread through the effects of their designs on people and environment no miner what their scale is [12]. Accordingly, the design education need to go beyond styling trends, consider environmental threats, recognize social and behavioral gaps and design to fill the gaps.

Some professional bodies like ARB/RIBA in UK and the Association of Danish Designers in Denmark recently acknowledged sustainability in their validation criteria but it is compartmentalized and relegated to technology subjects, rather than integrated into behavioral, social or cultural context. In this regard, some efforts are started by design communities in developed countries to translate rising public concern into action by changing their behavior to accommodate recycling or energy efficiency and by using environmental awareness as the main criteria of their design decisions. As an example, the Danish Designers’ Association includes responsibility for environmental and social issues in their membership criteria, and BEDA the Bureau of European Design Associations participated in the DEEDS project, which had the mission to embed sustainability in design and design in sustainability[1]. The “Applied Ecology” program at KTH, Royal Institute of Technology in Stockholm, Sweden[13], the “Sustainable Higher Education” at university of Ghent, Belgium[14], “Social Responsibility and Sustainability Strategy 2010-2020” at the University of Edinburgh[15], and the integration of DfS with industrial design courses at Delft University of Technology [16] are other examples. However, the efforts for DfS in developing countries is still insignificant comparing to developed countries. According to Deniz [12], environmental effects have been commonly ignored through design and planning stages in developing countries. In this case, developing countries need to consider new solutions for challenging traditional procedures through new way of design thinking and applications. Designers in these countries have responsibilities to not only consider environmental issues but also create environmental awareness throughout their societies. This role has been recognized and emphasized by the United Nations, when it proclaimed the Decade of Education for Sustainable Development (DESD).

5. A Case study of design for sustainability in education

This paper presents a case study in design education which explores how designers and design educators, especially in developing countries, can set their own holistic approach to sustainability in new product development, place social awareness, responsibility and behavior in perspective and provide an inspirational practices for student designers. The experience focuses on one particular course at Art university of Isfahan (AUI), Iran (Industrial Design Group, Bachelor curriculum). The course named ‘Design 5’ is exemplary for a regular street furniture and city installation design course, which was offered for many years in a broad spectrum of disciplines as aesthetics, ergonomics, manufacturability, market considerations, but not sustainability. The Design 5 course was singled out by the curriculum developers to be developed into a design course with an increased emphasis on environmental issues and sustainability. The new defined Design 5 course at AUI is to a large extend based upon the sustainability context. In this course, students gain a holistic perspective on their environmental responsibilities, and integrating sustainability issues into product design. Through this course, students are educated to become designers that affect and guide the society toward sustainability. The subject of the course is to design a city installation or street furniture which not only gives services to the public but acts as a facilitator to sustainability. The main objective of this course is to design street furniture which are not neutral but improve the sustainability within their context. In addition to applying eco-design criteria (e.g. Minimizing the environmental impact, using recycled and recyclable materials, extending product lifecycle), the students need to take into account the following strategies through their design:

- Raise public awareness of sustainability
- Educate and sensate public on sustainability
- Promote sustainable behavior with any of the design strategies for changing behavior, namely, coercive, decisive, persuasive, and seductive.

Figure 1 presents the spectrum from a not sustainable design to eco-design and socially responsible design. The students` design are guided to move toward the end of this spectrum for establishing a deeper level of sustainability in the society.

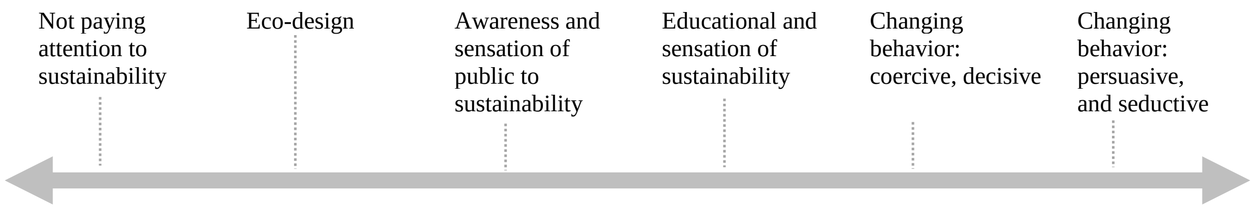

Fig1. Different levels of Design for Sustainability

6. Conclusion

As societal expectations have changed from narrowly focused environmental issues to broader sustainable development concerns, it is vital that future designers graduate with an understanding of how social impacts may affect or may be affected by their designs and decisions. It should be acknowledged that sustainable education need to have some type of a higher calling, which may be social responsibility and public design. Designers need to have heightened awareness of their contributions to environmental degradation. Accordingly, the conducted educational experiment at Art university of Isfahan (AUI) demonstrates the potential and usefulness of integrating sustainability into mainstream design practice and design education, and thereby providing the missing link between sustainable production and consumption. DfS will be offered to mainstream design education institutions to equip the next generation of designers with the necessary tools and skills in designing more sustainably.

The effectiveness of this practice, is expected to clear that sustainability was supposed to be more than just purely environmental issues, and should in general refer to 'beneficial to society'. This is explicitly to address social issues as well in particular including environmental issues. Accordingly, the course leads to expand design context in thinking and practice something beneficial for the society and set new aspirations, change perceptions of students by making use of the diversity of ”value-added' criteria's to design process.

In addition, the experience gained by the course demonstrates that substituting traditional design briefs for sustainability-oriented instructions broadened the horizon of students and led to an outburst of creativity and originality. DfS requires “thinking out of the box”, overcoming traditional habits, and this is a significant creativity stimulus. Putting theory into practice, making something out of nothing which, and the opportunity to choose a social-environmental problem as the main starting point of the project are among the main reasons for creativity.

In general, the Design 5 course received a positive evaluation. This is best illustrated by the outputs of the evaluation which reports that over 94% students judge either positive or very positive which led to pay much more attention to the deep sustainability. The percentage of students that stated that they had truly learned to integrate sustainability into product development was 86%. The results show that incorporating sustainability concepts in teaching Industrial design courses is not difficult and the students are more willing to understand the new concepts regarding sustainability.

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Designing for Construction Ergonomics in Slovenia

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Abstract

Relative to other industries worldwide, the construction process generates a disproportionate number of fatalities, injuries, and disease, and both the direct and indirect costs contribute to the cumulative cost of construction.

Designers influence construction ergonomics directly and indirectly. The direct influence is because of design, details and method of fixing, and depending upon the type of procurement system, supervisory and administrative interventions. The indirect influence is because of the type of procurement system used, pre-qualification, project duration, partnering, and the facilitating of pre-planning.

The purpose of the paper is to present the results of a study conducted among designers in Slovenia using a self-administered questionnaire, to determine their perceptions and practices relative to construction ergonomics. Descriptive statistics in the form of frequencies and a measure of central tendency were computed from the collected data.

The following constitute the salient findings. Cost, quality, and time are more important to designers than construction ergonomics and project health and safety (H&S). Ergonomics during the construction, and design phases are more important to designers than the other phases. A range of design related aspects impact on construction ergonomics. To a degree, construction ergonomics is considered on most design, procurement, and construction occasions by designers. Practice notes predominate in terms of how designers' ergonomics knowledge was acquired. A range of aspects have the potential to contribute to an improvement in knowledge, and the application of construction ergonomics.

The paper concludes that designers contribute to construction ergonomics, but that there is potential for and a clear need for enhanced contributions. Recommendations include the inclusion of construction ergonomics in designers' tertiary education, and continuing professional development (CPD), to remedy shortcomings in practitioners' knowledge.

Keywords: Construction; Designers; Ergonomics

1. Introduction

The Council Directive 92/57/EEC of 24 June 1992 on the implementation of minimum safety and health requirements at temporary or mobile constructions sites [1] states that unsatisfactory architectural and/or organizational options or poor planning of the works at the project preparation stage have played a role in more than half of the occupational accidents occurring on construction sites in the Community. This amplifies the need for 'designing for safety', which Behm [2] defines as "The consideration of construction site safety in the preparation of plans and specifications for construction projects."

Design is an important stage of projects, as it at this stage that conceptual ideas are ideally converted into constructable realities [3]. 'Designing for H&S' being one of the designing for constructability principles. Thorpe [3] further states that designing for safety is one of a range of considerations that need to be balanced simultaneously

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during design, and highlights that it is an integral part of the overall design process as doing so will result in safer construction and maintenance of structures and facilities.

Slovenian legislation and international literature highlight the relevance of designing for construction ergonomics, which resulted in a study that was conducted among designers, the objectives being to determine relative to respondents and their practices, the:

- Importance of project parameters;
- Importance of ergonomics during the various project phases;
- Frequency at which they consider construction ergonomics on various occasions and relative to various design related aspects;
- Extent to which various design related aspects impact on construction ergonomics;
- Source of ergonomics knowledge, and
- Potential of various aspects to contribute to an improvement in construction ergonomics.

2. Review of the literature

2.1. Recommendations pertaining to designers

The International Labour Office (ILO) [4] as early as 1992 recommended that designers should: receive training in H&S; integrate the H&S of construction workers into the design and planning process; not include anything in a design which would necessitate the use of dangerous structural or other procedures or hazardous materials which could be avoided by design modifications or by substitute materials, and consider the H&S of workers during subsequent maintenance.

2.3 Designing for construction ergonomics

H&S through design is a fundamental principle of ergonomics, and the hierarchy of controls is fundamental to the process of hazard reduction i.e. elimination or substitution to mitigate hazards [5]. Although architects and engineers regularly address ergonomics in their designs, their concerns apply almost exclusively to the end-user of a facility, rather than the workers who undertake the construction thereof [5].

2.4. The impact of design on construction ergonomics

Design influences and impacts on construction H&S directly and indirectly. Directly through: concept design; selection of structural frame; detailed design; selection of cladding, and specification of materials. Indirectly through: the selection of procurement system; related interventions such as prequalification; decision regarding project duration, and selection of contractor [6].

A study conducted in the USA to determine whether addressing H&S in the project designs could have prevented incidents, entailed the analysis of 450 reports of construction workers' deaths and disabling injuries [2]. The analysis determined that in 151 cases (33.6%), the hazard that contributed to the incident could have been eliminated or reduced if 'design-for-H&S' measures had been implemented.

2.5. Importance of Health and Safety

Research findings indicate that historically, the traditional project parameters of cost, quality, and time, have taken precedence over H&S, including ergonomics, in terms of the importance of project parameters. During 'The Influence of Architectural Technologists on Construction Ergonomics' study conducted by Smallwood [7], end-user ergonomics, and construction ergonomics were ranked third and seventh respectively in terms of the importance of seven project parameters. Then, construction, commissioning, and deconstruction were ranked third to fifth in terms of the importance of ergonomics during five building / structure phases.

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3. Research

3.1. Research method and sample stratum

172 Active design practices in Slovenia constituted the sample stratum. 33 Responses were received and included in the analysis of the data, which equates to a response rate of 19.2%. The analysis of the data consisted of the calculation of descriptive statistics to depict the frequency distribution and central tendency of responses to fixed response questions.

It should be noted that construction ergonomics refers to ergonomics during the phases of construction, commissioning, maintenance, and deconstruction, and end-user ergonomics refers to ergonomics during the use of the building / structure.

A previous study conducted among architectural technologists in South Africa to determine their perceptions and practices with respect to construction ergonomics investigated the: frequency at which construction ergonomics is considered on various occasions and relative to various design related aspects; extent to which various design related aspects impact on construction ergonomics; source of ergonomics knowledge, and the potential of various aspects to contribute to an improvement in construction ergonomics [7]. The study reported on constitutes a replication of this South African study, which study in turn constitutes the origin of the occasions, aspects, and sources.

3.1. Research findings

Table 1 indicates the importance of seven project parameters to respondents in terms of a mean score (MS) ranging between 1.00 and 5.00, and percentage responses to a scale of 1 (not important) to 5 (very important). It is notable that the MSs are all above the midpoint of 3.00, which indicates that in general the respondents perceive the parameters as important. However, given that the MSs for the top four parameters are > 4.20 ≤ 5.00, the respondents can be deemed to perceive them to be between more than important to very important / very important. It is notable that two of the three traditional project parameters, namely project quality, and project cost are ranked within the top three and project quality first. Project time is ranked fourth. The parameters ranked fifth to seventh have MSs > 3.40 ≤ 4.20, therefore the respondents can be deemed to perceive them to be between important to more than important / more than important. It is also notable that construction ergonomics, the subject of the study is ranked seventh – last, and after end-user ergonomics.

Table 1. Degree of importance of project parameters to respondents' practices.

Parameter	**Response (%)**					**MS**	**Rank**
	Not…...………………………………………Very						
	1	**2**	**3**	**4**	**5**		
Project quality	4,8	0	4,2	23,5	67,5	4,49	1
Project health and safety (H&S)	3.6	1,0	10,2	29,7	55,5	4,33	2
Project cost	2,0	4,0	12,3	29,4	52,3	4,26	3
Project time	4,0	1,0	11,1	35,3	48,6	4,24	4
Environment	2,1	6,3	26,4	38,8	26,4	3,81	5
End-user ergonomics	6,7	5,1	29,4	32,5	26,3	3,67	6
Construction ergonomics	8,2	4,0	36,7	36,7	14,4	3,45	7

Table 2 indicates the importance of ergonomics to respondents during the various project phases in terms of a MS ranging between 1.00 and 5.00, and percentage responses to a scale of 1 (not important) to 5 (very important). It is notable that except for deconstruction, the MSs are all above the midpoint of 3.00, which indicates that in general the respondents perceive ergonomics to be important during the related project phases.

No phases fall within the range > 4.20 ≤ 5.00 - between more than important to very important / very important. Construction, design, use, and maintenance fall within the range > 3.40 ≤ 4.20 - between important to more than important / more than important. Deconstruction in turn, falls within the range > 2.60 ≤ 3.40 - between less than important to important / important.

Table 2. Degree of importance of ergonomics during project phases to respondents' practices.

Phase	Response (%) Not…...………………………………………Very					MS	Rank
	1	2	3	4	5		
Construction	6,5	4,1	9,6	49,2	30,6	3,93	1
Design	6,8	2,6	20,9	31,0	38,7	3,92	2
Use	6,8	4,0	11,8	38,9	36,2	3,87	3
Maintenance	5,9	7,0	19,7	35,0	32,4	3,81	4
Deconstruction	24,2	15,2	31,0	18,5	11,1	2,77	5

Table 3 presents the frequency at which respondents consider or refer to construction ergonomics on fourteen occasions in terms of a MS ranging between 1.00 and 5.00, and percentage responses to a frequency range of never to always. The project phase within which the occasion falls is referenced between parentheses in terms of stream: upstream (Up); midstream (Mid), and downstream (Down). It is notable that 11 / 14 (78.6%) MSs are above the midpoint of the range, namely 3.00, which indicates the consideration of or reference to construction ergonomics on these occasions can be deemed to be frequent as opposed to infrequent.

It is notable that no occasions fall within the range > 4.20 ≤ 5.00 – between often to always / always. Only 3 / 14 (21.4%) fall within the range > 3.40 ≤ 4.20 – between sometimes to often / often. However, it is also notable that one of the top three occasions is 'midstream', and two are 'upstream'. The remaining occasions fall within the range > 2.60 ≤ 3.40 – between rarely to sometimes / sometimes. A further three 'upstream' occasions are ranked 4th to 6th. 'Upstream' occasions are ideal as it the stage at which construction ergonomics can be mostly influenced.

Table 3. Frequency at which respondents' practices consider or refer to construction ergonomics on various occasions.

Occasion	Response (%) Never	Rarely	Some-times	Often	Always	MS	Rank
Preparing project documentation (Mid)	7,7	5,6	27,2	38,1	21,4	3,60	1
Detailed design (Up)	7,8	6,4	26,7	38,0	21,1	3,58	2
Design (Up)	8,0	7,9	24,0	49,3	10,8	3,47	3
Design coordination meetings (Up)	9,5	8,0	31,5	40,1	10.9	3,35	4
Constructability reviews (Up)	10,8	16,4	24,7	35,2	12,9	3,23	5
Deliberating project duration (Up)	14,1	11,5	24,9	36,4	13,1	3,23	6
Pre-qualifying contractors (Mid)	9,6	16,0	31,9	26,7	15,8	3,23	7
Client meetings (Up)	10,1	12,8	36,5	29,9	10,7	3,18	8
Working drawings (Up)	9,6	16,3	44,1	13,7	16,3	3,11	9
Site handover (Mid)	11,2	19,1	29,4	30,0	10,3	3,09	10
Evaluating tenders (Mid)	10,4	23,6	25,3	30,4	10,3	3,07	11
Site inspections / discussions (Down)	11,4	25,1	33,3	14,8	15,4	2,98	12
Pre-tender meeting (Mid)	11,5	30.1	25,3	22,4	10,7	2,91	13
Site meetings (Down)	13,0	21,1	33,4	26,5	6,0	2,91	14

Table 4 indicates the perceived impact of sixteen design related aspects on construction ergonomics in terms of a MS ranging between 1.00 and 5.00, based upon percentage responses to a scale of 1 (minor) to 5 (major). It is notable that all sixteen MSs are above the midpoint of 3.00, which indicates the respondents perceive the design related aspects to impact on construction ergonomics.

It is notable that no MSs fall within the range of > 4.20 ≤ 5.00 - between a near major to major impact / major impact.

Only four (25%) aspects fall within the range > 3.40 ≤ 4.20, which indicates that they have between an impact and a near major impact / near major impact on construction ergonomics - site location, details, type of structural frame, and design (general). Type of structural frame was identified as the stage that impacts most on construction ergonomics during a study conducted by Smallwood [8].

The remaining 12 / 16 (75%) of aspects' MSs are > 2.60 ≤ 3.40 - between a near minor impact to some impact / some impact on construction ergonomics. Notable rankings include surface area of materials (twelfth), and mass of materials (sixteenth), as these have a major effect in terms of manual handling.

Table 4. Extent to which various design related aspects impact on construction ergonomics.

Aspect	Response (%) Minor……………………Major					MS	Rank
	1	2	3	4	5		
Site location	10,1	5,2	10,1	41,3	33,3	3,83	1
Details	8,0	3,0	33,2	32,9	22,9	3,60	2
Type of structural frame	8,0	3,0	30,5	40,5	18,0	3,58	3
Design (general)	8,0	8,0	20,7	45,5	17,8	3,57	4
Position of components	10,2	5,2	38,4	32,9	13,3	3,34	5
Finishes	8,0	10,0	36,3	33,0	12,7	3,32	6
Plan layout	10,0	13,0	33,4	22,8	20,8	3,31	7
Method of fixing	12,7	8,1	40,8	12,7	25,7	3,31	8
Content of material	9,6	0,0	50,4	31,9	8,1	3,29	9
Elevations	8,0	12,7	44,2	14,6	20,5	3,27	10
Texture of materials	10,1	8,0	46,3	25,7	9,9	3,17	11
Surface area of materials	9,9	8,1	43,5	33,4	5,1	3,16	12
Edge of materials	7,9	9,8	45,8	31,4	5,1	3,16	13
Schedule	12,6	20,8	25,8	22,7	18,1	3,13	14
Specification	8,0	22,5	29,5	30,5	9,5	3,11	15
Mass of materials	12,2	8,0	50,2	24,9	4,7	3,02	16

Table 5 presents the frequency at which respondents consider / refer to construction ergonomics relative to sixteen design related aspects, in terms of a MS ranging between 1.00 and 5.00, and percentage responses to a frequency range of never to always. It is notable that all sixteen MSs are above the midpoint of 3.00, which indicates consideration of / reference to H&S relative to these design related aspects can be deemed to be frequent as opposed to infrequent.

It is notable that no occasions fall within the range > 4.20 ≤ 5.00 – between often to always / always, and similarly within the range > 3.40 ≤ 4.20 – between sometimes to often / often.

All the aspects fall within the range > 2.60 ≤ 3.40 – between rarely to sometimes / sometimes. Site location, method of fixing, and details predominate, and are ranked in the top three. They are followed by specification, and type of structural frame, the latter being notable as it is the stage that impacts most on construction ergonomics (Smallwood, 2002). Along with design (general) ranked eighth it provides the framework for a project in terms of construction ergonomics. Given that certain materials contain hazardous chemical substances it is notable that content of material achieved a ranking of thirteenth. Furthermore, given that materials handling, and more specifically the mass of materials contributes to manual materials handling, it is also notable that mass of materials has a MS marginally above the midpoint of 3.00 (3.04), and was ranked eleventh. Similarly, given that the surface area of many materials required for certain elements such as gypsum boards for ceilings and partitions, and glazing for shop fronts is large, the MS of 3.01 is notable. However, it should be noted that finishes and schedule, which encapsulate materials and processes, achieved rankings of seventh and ninth respectively.

Table 5. Frequency at which respondents' practices consider or refer to construction ergonomics relative to various design related aspects.

Aspect	Response (%)					MS	Rank
	Never	Rarely	Some-times	Often	Always		
Site location	10,7	12,8	20,4	39,0	17,1	3,39	1
Method of fixing	22,2	9,1	36,4	21,5	10,8	3,39	2
Details	11,0	11,0	23,9	41,3	12,8	3,34	3
Specification	8,7	15,1	33,0	30,3	12,9	3,24	4
Type of structural frame	10,9	15,6	27,2	33,1	13,2	3,22	5
Plan layout	9,0	15,1	32,7	32,6	10,6	3,21	6
Finishes	13,1	11,3	27,1	39,1	9,4	3,20	7
Design (general)	11,0	13,2	37,3	29,7	8,8	3,12	8
Schedule	15,4	13,3	30,2	28,2	12,9	3,10	9
Elevations	19,5	13,0	24,4	29,9	13,2	3,04	10
Mass of materials	12,9	19,7	32,5	20,1	14,8	3,04	11
Edge of materials	15,1	10,7	37,3	30,1	6,8	3,03	12
Texture of materials	13,5	13,5	39,5	24,8	8,7	3,02	13
Content of material	15,1	10,6	41,2	24,1	9,0	3,01	14
Surface area of materials	14,9	7,0	47,5	23,6	7,0	3,01	15
Position of components	14,8	12,7	33,1	35,4	4,0	3,01	16

Respondents were required to indicate their knowledge of 'ergonomics' in terms of percentage responses to a scale of 1 (limited) to 5 (extensive). The resultant MS of 2.77 is > 2.60 ≤ 3.40, whichindicates the knowledge can be deemed to be between less than average to average / average. However, 2.77 falls marginally above the lower range > 1.80 ≤ 2.60 - between limited to less than average / less than average.

Table 7 indicates that experience (75.8%) predominates in terms of respondents' source of ergonomics knowledge, followed by experience (51.5%) and magazine articles (36.4%). The remaining resources attracted less than a third response.

Table 7. Respondents' source of ergonomics knowledge.

Source	Yes (%)
Practice notes	75.8
Experience	51.5
Magazine articles	36.4
Journal papers	24.2
Conference papers	21.2
Workshops	18.2
Tertiary education	15.2
Other	6.1
Post graduate qualifications	6.1
CPD seminars	3.0

Table 8 indicates the potential of various aspects / interventions to contribute to an improvement in construction ergonomics during the various project phases in terms of a MS ranging between 1.00 and 5.00, and percentage responses to a scale of 1 (minor) to 5 (major). The letters inserted within parentheses denote whether the aspect / intervention is design (D), procurement (P), construction (C), or multi-phase related. It is notable that all the MSs are above the midpoint of 3.00, which indicates that in general the respondents perceive the various aspects / interventions to have the potential to contribute to an improvement in construction ergonomics during the various project phases.

General design, awareness, and contractor planning predominate, and their MSs are > 3.40 ≤ 4.20 – between potential to near major potential / near major potential to contribute. It is notable that the top ranked aspect / intervention is design phase related, the second construction and design, the third, construction, related, and that the fourth and fifth aspects / interventions, details and constructability (general), are design related.

Table 8. Potential of various aspects / interventions to contribute to an improvement in construction ergonomics during the various project phases.

Aspect / intervention	Response (%) Minor.......Major					MS	Rank
	1	2	3	4	5		
General design (D)	6,0	0,0	19,4	42,3	32,3	3,95	1
Awareness (C & D)	10,0	0,0	23,3	31,6	35,1	3,82	2
Contractor planning (C)	6,1	3,0	23,2	44,6	23,1	3,76	3
Details (D)	6,0	0,0	39,1	39,1	15,8	3,59	4
Constructability (general) (D)	6,1	3,3	35,2	39,3	16,1	3,56	5
Design of equipment (construction) (C)	6,1	3,1	39,3	45,3	6,2	3,42	6
Safe working procedures (C)	10,0	12,9	23,0	34,7	19,4	3,41	7
Reengineering (C, D & P)	6,2	6,2	36,0	45,4	6,2	3,39	8
Mechanisation (C & D)	6,1	10,3	31,9	45,5	6,2	3,35	9
Design of tools (construction) (C)	6,0	13,3	39,0	28,6	13,1	3,30	10
Workshops on site (C)	10,0	12,8	25,7	41,5	10,0	3,29	11
Prefabrication (D)	6,2	13,3	42,1	25,2	13,2	3,26	12
Specification (general) (D)	6,1	19,4	32,3	36,1	6,1	3,17	13

79.2% of Respondents were familiar with the Slovenian 'Health and Safety Work Act' and 20.8% were not. 55.9% were familiar with the ergonomic provisions of the construction and design regulations related to their work, and 44.1% were not.

4. Conclusions

The traditional project parameters of quality, cost and time are more important than construction ergonomics to designers. However, project H&S was ranked second. Therefore, it can be concluded that designers do not understand and appreciate the synergy between project H&S and ergonomics, and the other parameters.

Construction ergonomics is more important during the construction and design stages than the use, maintenance, and commissioning phases, and therefore the focus is likely to be more on the former than the latter phases.

Designers do consider construction ergonomics on various occasions, however, more so during upstream phases than mid-stream phases, design included. Therefore, it can be concluded that the cited importance thereof does manifest itself. However, the frequency is mostly between rarely to sometimes / sometimes.

Designers consider construction ergonomics on various design related occasions. However, the frequency is mostly between rarely to sometimes / sometimes. The frequency relative to mass of materials is notable and is possibly attributable to a lack of knowledge of the mass of materials.

Designers do appreciate the extent to which various design related aspects impact on construction ergonomics to a degree in that they maintain most design related aspects have between a near minor impact to some impact / some impact thereon.

Furthermore, given the divergent rankings between the perceived impact of design related aspects on construction ergonomics, and the consideration / reference to such aspects, it can be concluded that designers' actions are not always based on a structured process such as documented design hazard identification and risk assessment.

Given the sources of architectural technologists' ergonomics knowledge it can be concluded that the sources are more informal than formal – practice notes, experience, and magazine articles, vis-à-vis tertiary education. It can also be concluded that tertiary designer education and the design professions are not addressing ergonomics to the extent that they should. These conclusions are reinforced by the designers' 'below average' self-rating of their knowledge of ergonomics.

Given the perceived potential of various aspects / interventions to contribute to an improvement in construction ergonomics, it can be concluded that designers, to a degree, do appreciate the potential of various design, procurement and construction practices to contribute to an improvement in construction ergonomics.

5. Recommendations

Designers' tertiary education should address construction H&S and ergonomics, and highlight the role thereof in overall project performance. Furthermore, designing for construction H&S and ergonomics should be introduced and more importantly, embedded in designer tertiary education programmes.

Designer professional associations / institutions should evolve construction H&S and ergonomics practice notes, and promote continuing professional development (CPD relative to construction H&S and ergonomics.

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Developing of evolution analysis algorithms in regenerative design and decision-making; demonstrated through a case study in Shiraz, Iran

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Abstract

Over the last decade the concept of 'Regenerative Design and Decision-Making' has been introduced as a mind-set which considers the integration of all humans' activities and natural systems, in a broader vision than the classic concept of 'Sustainability' (mostly focused on the present). This vision identifies a greater scope, considering 'Regenerative' as a package of 'sustainable for today', 'sustainable for future', and 'heal the past'. The 'system evolutions' and uncertainty of changes, are key factor to be considered in designing of required infrastructures of sustainability for future and healing the damages to the economy, society and environment in the past. this in turn, highlights the role of 'Evolution Analysis (EA)' and 'Future Identification (FI)' in regenerative developments.
A practical solution for FI is to develop EA algorithms, to be applied to identify the rates of changes over the integrating flows, through projects' time-frames in a more precise way. This in turn, saves huge rates of resources through design and implementation of extra infrastructures, to deal with future changes; as well as supporting the decision-makers to reach more realistic solutions, with higher levels of precision.
This paper focuses on a real case-study, the Faculty of Art and Architecture campus, in Shiraz University, Shiraz, Iran, as a part of an evolution analysis research project, sponsored by 'Iran's National Elites Foundation', and the solutions to deal with the real-projects' limitations, such as disorganisation/lack of History Data (HD), stored by different teams over a ten-year period of the campus history. Such limitations, are principally caused by 'changes in management systems', as a key integrating flow in systems' lives, and cause of uncertainties in FI.
Indeed, the paper demonstrates some critical and practical solutions, to develop EA algorithms for Regenerative Design and Decision-Making in real practices.

Keywords: Evolution analysis algorithms, future identification, history data, management strategy change, regenerative design and decision-making

1. Introduction

During the last century the global of industrialisation has caused some un-wanted negative impacts on human socio-economic behaviours as well as the global environment. Although The 'Sustainability Concept' (also introduced as 'green design' concept in many literatures) has tried to address the resource consumptions (such as energy, water, food etc.) and preventation of the further socio-economic and environmental impacts, the previous one-century damages are still existing. This in turn, has translated into a further solution recently introduced as 'Regeneration' or 'Regenerative Developments' (RD) [1, 2] . The main challenge of RD is to provide and to consider the potentials for 'Renew', 'Re-

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birth' and 'Recover' the previously caused damages to human socio-economic relations as well as the environment. Accordingly, the regeneration concept intends on further than 'generation-consumption' systems (see figure1). Therefore, in order to be regenerative, a system must provide the factors such as 'being sustainable for today', 'being sustainable for tomorrow', and 'recovering the previously caused damages on economy, society and environment'.

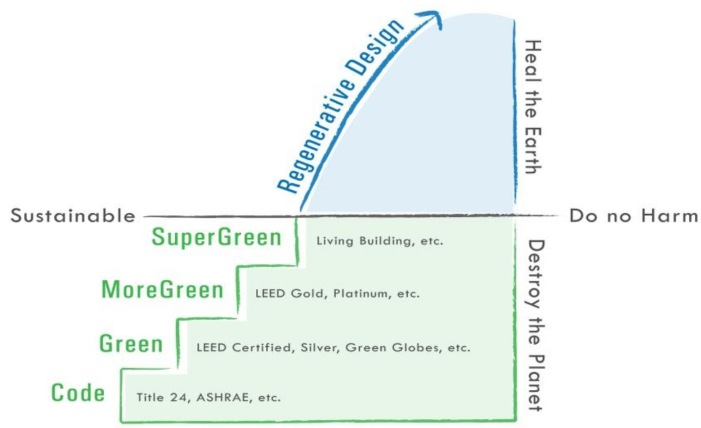

Fig. 1. Regenerative vs. Sustainable; the general concept [3].

Therefore, a set of "resource-related strategies within cycles – from nature and back to nature" have been proposed as follows:

- "Produce: resources are renewable and are sourced or generated either onsite or locally.
- Use: resources are used effectively in satisfying human needs.
- Recycle: resources are used for multiple purposes and benefits.
- Replenish: rather than diminish natural capital during the production of resources and assimilation of 'waste', replenishes and builds natural capital."[4, 5]

Regenerative Design considers a much more complex set of potential exchanges associated with both Net Zero and Net Positive systems. Accordingly, the impacts are being assessed in the following ways [5]:

- Grid-connected impacts: includes all inter-connections of the system/s with their surrounding system/s and neighbourhoods and exchanges of energy, water, wastes etc. "Grid connection is a necessary and core requirement of net zero/[positive] energy buildings" [5].
- Waste scavenging: includes spotting the wastes and problems within the existing systems and infrastructures to prevent further damages. This process considers the improvements of 'quality of performance' within the system/s exchanges and the 'quality of Net expectation'.
- Recovery potentials: includes adding of potentials and new infrastructures as well as improvement of the existing systems and/or infrastructures to achieve a faster recovery of the previously caused damage to the assessing society/ies, environment and economic system.

The optimisation factors of RD are as follows:

- Covering all requirements of a sustainable system such as economic, social and environmental preservation;
- Considering and providing of infrastructures to address the future requirements of systems, based on future identification;
- Recovering of the existing omissions in-with the systems, caused in past events.

In contrast with Sustainable Developments, the Regenerative system considers the human and environmental activities as 'inter-related flows', and the impact of each flow on the others in a greater scale (See figure 2).

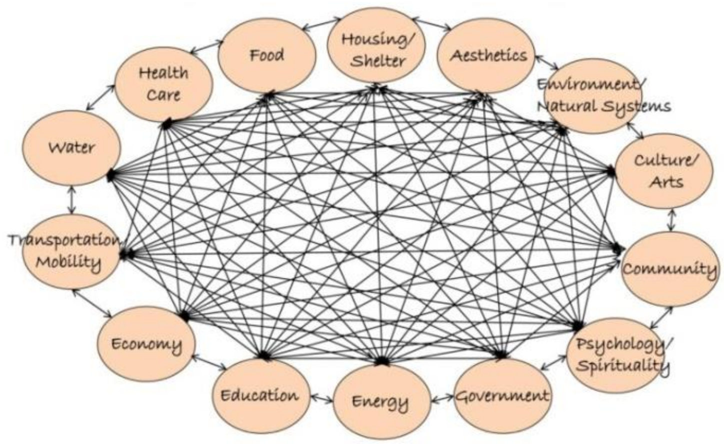

Fig. 2. the inter-relation of the flows in a Regenerative Community [6]

1.1. Role of Evolution and Future Identification

As the Regenerative Design intends to provide a better system which recognizes human as a part of the 'ecosystem'; and respects to the need of human to be incorporated into it. This in turn, is being translated into another model for sustainable living "that relies on synergy, or the idea of separate components forming a whole that is greater than the sum of its parts. It emphasizes patterns and groupings that occur naturally"[7]. Accordingly, the Regenerative Design attempts to consider the evolutions within and out-with its assessing system/s. "[t]he All these ideas combine to create patterns that mimic nature so that humans can take a symbiotic role in their environment rather than a destructive one. Obviously, a perfect closed system that regenerates itself 100 percent is not mathematically possible, so the current goal is 99.9 percent regeneration. Even that goal is a challenging one, but the process of attempting it is viable, and the result of not adapting to a changing environment is very clearly demonstrated in history: it is extinction" [7] (See figure 3).

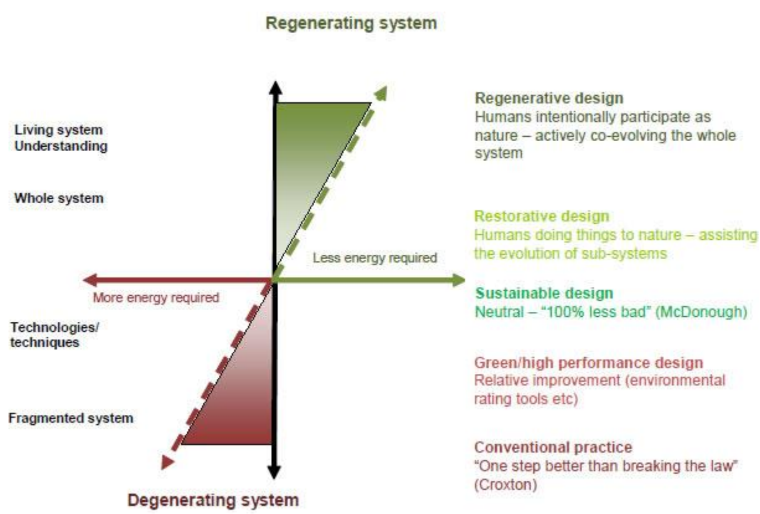

Fig. 3. the evolution-based view of RD [8].

As previously stated, one of the main attributions of regenerative design is to have a 'net positive' system, which considers in 'providing potentials to deal with future changes' and 'to recover the previously caused damages to environment, society and economy. This in turn, identifies the great demand for 'anticipation and pre-assessment' of the future events. This demand principally comes from the need of market to secure the investments on extra infrastructure for dealing with possible future changes and events. However, the role of uncertainty is supposed to be considered. In comparison with the length of human life, the systems contain very long-term service-lives. As shown in figure 4 a typical building neighbourhood (as a system example) can face several changes during its service-life. These changes can be greater and more diverse regarding the longer proposed building timeframes.

The aforementioned changes can be considered in following factors/flows: Population, building occupation and functional changes, end-users' behaviours, ethnics and culture, environmental changes (such as temperature, rain and snow, wind, green area type, lakes, rivers etc), technology changes (utilities' technology, in-site and out-site energy generation system/s, wireless systems etc.), market changes etc. [9, 10]. Moreover, the new developments in a neighbourhood/system will change the traffic and energy-water-waste management systems. Furthermore, the level of pollutions and time-based strategies of pollution management will be altered.

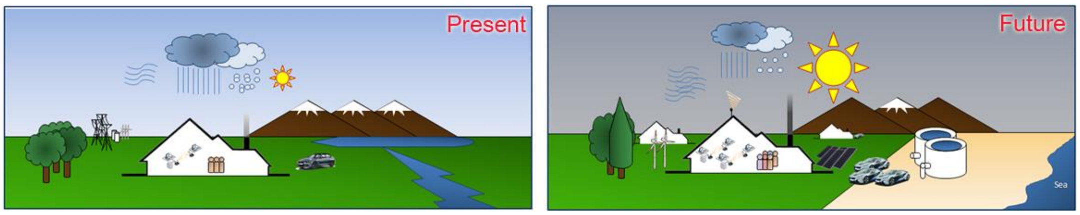

Fig. 4. a comparison of internal and external influences on a building in a typical timeframe [11].

2. Regenerative life cycle assessment: development of a critical evolution analysis algorithm

Established on level of complexity, parameters of interest, and number of optimization factors in-with each system, detailed mathematical models are being developed, which describe the components' interactions, properties of the environment and the goals that one wants to achieve. These goals may include; minimizing the resource consumptions, generating the least possible pollution, maximizing the number of housings in a limited urban area and etc. The proposed algorithm subject of this paper includes two major phases as follows.

2.1. Data Pre-processing Phase

In Real practice, data is highly susceptible to missing and inconsistent values due to their origins, multiple and heterogeneous resources, lack of valid information and human errors. Therefore, data pre-processing is a fundamental phase to improve the quality of data and the accuracy of algorithms.

Data pre-processing includes variety of steps such as data cleaning, data integration, etc.

In cases such as proposing algorithm with specific 'energy' intention, a disaggregation phase is being added in to the process, depending on data quality and availabilities of assessment values for affecting flows.

To disaggregate total consumptions, the consumption ratio for each flow of energy in the whole dataset must be calculated and accordingly, it is possible to calculate and assign the consumption for each flow. Figure 5 reveals the full procedure of Pre-processing phase in development of a typical Evolution Analysis Algorithm.

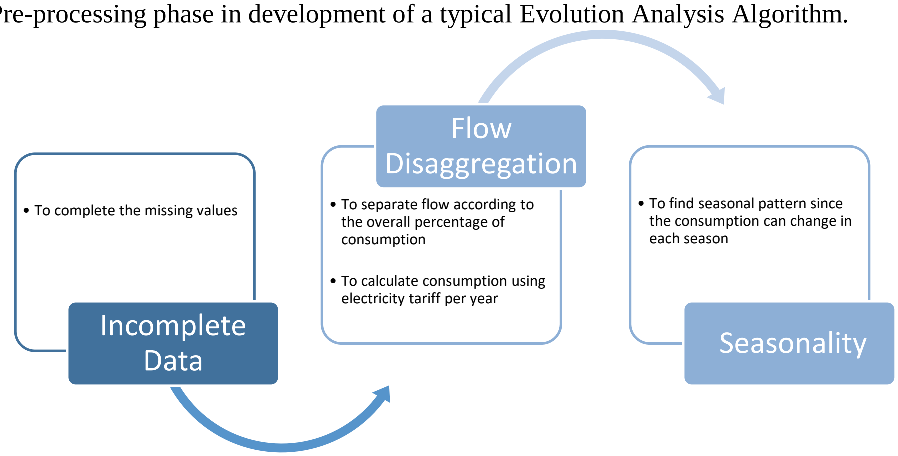

Fig. 5. Pre-processing phase in development of a typical Evolution Analysis Algorithm

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2.2. Forecasting Phase

Forecasting is considered as a common task in several areas of 'Evolutionary Flows' such as business, transportation, production, etc. It is an approach to predict the future events as accurate as possible, using the resulted knowledge from data extraction and history-data to be employed as an integral part of greater and complex systems. Basically, forecasting methods and algorithms can be extremely simple or highly complex. Moreover, choosing of a proper algorithm depends on dataset, goals and plans of a project.

This paper compares and evaluates two forecasting methods, methods of Genetic Algorithms (GA), a previously introduced algorithmic approach based on GA [12], vs. Artificial Neural Networks (ANN), to examine the reliability of each to be applied into RLCA. In 2015 Kashkooli et.al[12] introduced a GA as a practical algorithm to be applied in-to the future identification of RLCA, as the two GA operation parts of crossover and mutation; in order to provide the best solutions to address the following goals.

- Survive
- Combine
- Generate a better solution

However, there are several limitations and deficiencies. Therefore, the fitting models should be generated and tested separately from GA, in advance. This in turn, can be time-consuming. Moreover, that would be difficult to develop a practical GA-based system to predict the evolution of flows accurately and efficiently, when the flows create a dense network (See figure 2). As a result, it has been understood that the ANN systems (inspired from brains' neural networks) can be considered as a more practical solution to identify the ratios and levels of future changes, as a part of RLCAs. In addition, the aforementioned ANNs are significantly adaptive to the network regarding to the variety of affecting flows. A critical distinction between the aforementioned ANN and the previously stated GA is in their capabilities to be adapted in-to greater networks, because of the fitting models, learning and forecasting capabilities of ANN.

3. Case-Study

To continue, this paper focuses on the 'Evolution Analysis Project at Faculty of Art and Architecture, Shiraz University', as a real case study, located in Shiraz, Iran. This project has been started on September 2017. The principal goal of the project is to design a platform for a practical tool for realistic future identification, to be employed to regenerative design and decision making. Therefore, the project intends to develop a regenerative set of algorithms, to analyse the evolution in-with the systems, with the highest levels of adaptability to unlimited affecting flows. As a sample flow, the research has considered the cost of resource consumption in–with the academic campus of Faculty of Art and Architecture at Shiraz University (See figure 6).

Fig. 6. academic campus (left) and main building (right) of Faculty of Art and Architecture at Shiraz University

3.1. Case-study pre-processing phase

At this stage the dataset of the case-study has been gathered, as a time series of four attributes such as 'start date', 'end date', 'name of flows', and 'cost' (As revealed in Formula 1). A sample of the prepared dataset is identified in figure 7.

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$$l = [\text{start - date.end - date.flow. cost}] \quad (1)$$

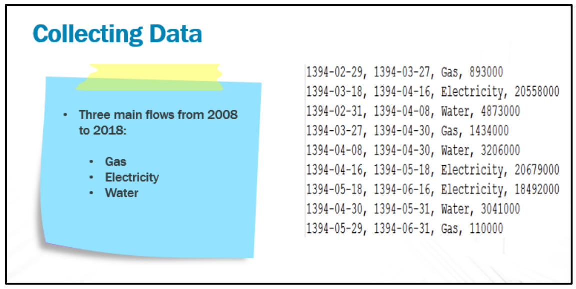


Fig. 7. a sample of dataset: Case-study of academic campus of Faculty of Art and Architecture at Shiraz University

To tackle the data omissions in values such as ‘start date’ or ‘end date’ (also known as ‘Missing values’), the missing fields have been estimated established on the ratios of the similar values, which can be found in the other parts of the gathered data. Such omissions are often made by casualties in data storing at the accounting departments, and are mostly caused by changes of management systems/human errors over the projects’ time scopes.

Furthermore, in some tuples, the values of cost are aggregated of two or three flows. In such cases, it is necessary to disaggregate the costs and consumptions by calculating the consumption ratio of each flow.

At this point, the assumption has been made in basis of applying the rates of highest usages and consumption tariffs into estimation of consumption. Since resource consumptions are presented by their costs in our dataset, and cost is not a reliable factor to forecast, the flow with highest usage has been considered and applied. As table 1 argues, the ‘Electricity’ has the highest usage among the flows.

Table 1. Flow consumption ratio

Flow	Consumption Ratio
Electricity	76%
Gas	18 %
Water	6%

To describe out time series dataset, specific patterns such as ‘seasonality’ and ‘trend’ should be recognised. In this case-study, the significant effects of weather conditions, temperature and season changes (known as ‘seasonality’ impacts) must be considered. Thus, the effect of ‘seasonality’ has been detected in calculations of the total consumptions (See figures 8 and 9). As it is shown in figure 8, electricity consumption increases in summer because of the usage of air conditioner and other cooling systems.

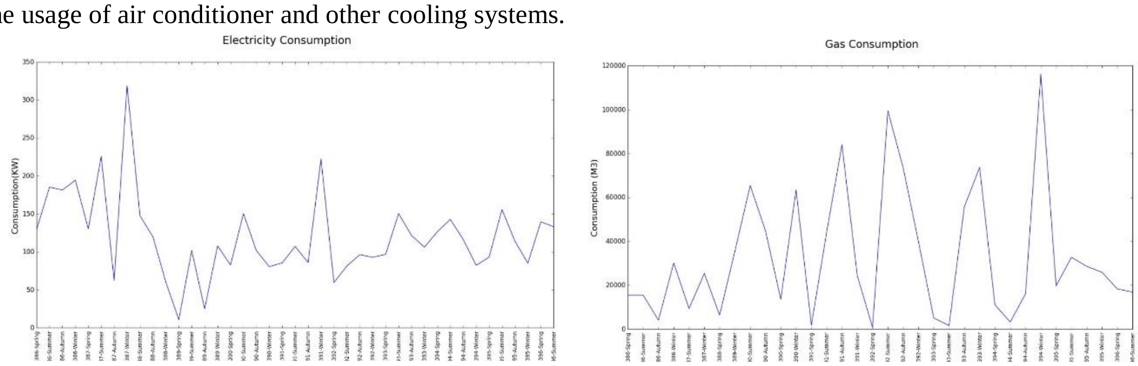


Fig. 8. seasonality in electricity and gas consumption between September 2008- September 2018: Case-study of academic campus of Faculty of Art and Architecture at Shiraz University

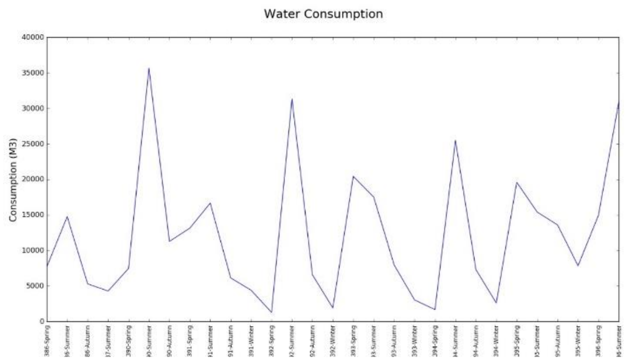
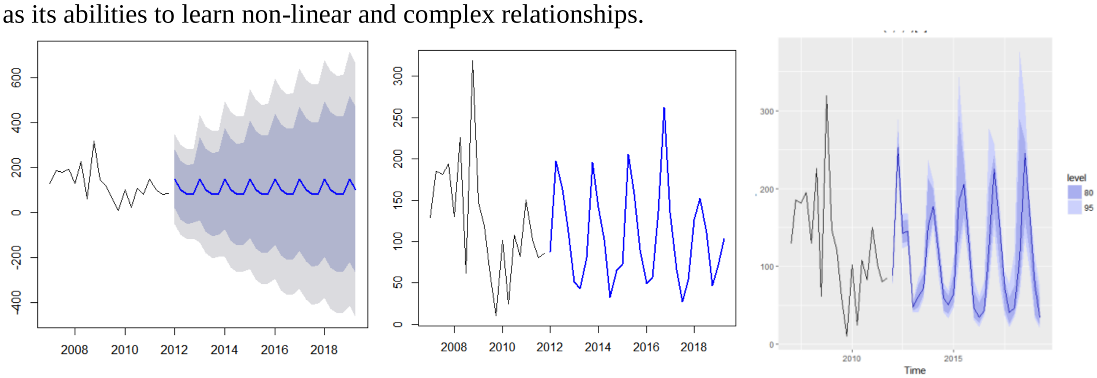


Fig. 9. seasonality in Water consumption between September 2008- September 2018: Case-study of academic campus of Faculty of Art and Architecture at Shiraz University

3.2. Case-study forecasting phase

At this phase, to validate the practicality of the three RLCA forecasting algorithms, they have been tested and compared with the real metered consumption data i.e. half of the data (from 2008 to 2012) have been considered to generate models for algorithms, and to anticipate the changes over their next five years (from 2012 to 2018). The first algorithm is based on 'seasonal naïve forecasting (SNF) method' that fails to predict future consumptions, as its predicted values are significantly different with the real recorded consumption values. The second algorithm, specific class of 'autoregressive moving average (AMA) method', is able to predict future consumptions more accurate in comparison to the previous method (naïve forecasting method).

In order to provide higher level of precision adaptability to the other integrating flows, a critical algorithm has been developed established on Artificial Neural Network (ANN), which is inspired from the structure of neural network in human's brain. As it is figure 10 revels, among the performed forecasting methods, the ANN provides the highest precision in predicting the future consumption. This capability is caused by the ANN's high levels of self-organisation, as well as its abilities to learn non-linear and complex relationships.



SNF method AMA method ANN method

Fig. 10. a comparison of the three method of RLCA forecasting algorithms: Case-study of academic campus of Faculty of Art and Architecture at Shiraz University

4. Discussion

The 2015 paper argued the practicality of Genetic algorithms (GA), introduced by Kashkooli et al., 2015 [12]. Therefore, the typical omissions of aforementioned GA have been investigated. Such omissions have been translated into the demands to shift into the other generation of EAs, and to benefit from ANN in order to provide more realistic and practical results for future identification systems. The results of such algorithms can be applied into the design and decision-making 3D modelling programmes (See figure 11) to identify a more realistic future. This identification can support the designers and decision-makers to design better infrastructures to practically deal with the future changes.

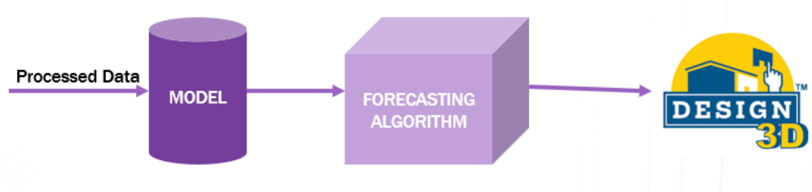


Fig. 11. general process applying the EA algorithms to design and decision-making 3D modelling programmes

5. Conclusion

In conclusion to develop a practical Regenerative LCA algorithm the following factors must be considered:

- Clear modelling of the previous stories of the systems, which are introduced as 'evolutionary flows', based on reliable data sources;
- Developing of the algorithms with high capacities and flexibilities to be developed, merged and adapted with other EA algorithms. This in turn, supports the EAs to consider as more flows as possible, in order to reach more practical and realistic results of future identification.

This research opened new door to further studies in subjects such as 'Future identification programmes and technologies'.

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Development of the prediction model of workers with fatal accident at construction site using machine learning

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Abstract

In the Republic of Korea, the industrial accident rate and the number of casualties in the construction industry have continued to increase for six years from 2011. The average industrial accident rate is 26.44% and the average number of casualties is 24,183. To prevent accidents, the Ministry of Employment and Labor (MOEL) presents various analysis data through the annual industrial accident report, but this has not been effective in reducing accidents as a result. In this paper, using the Logistic regression model that is one of the Machine learning method, this study develops a construction accident prediction model by training 80% of the data of accident casualties (25,114 persons) and accident deaths (499 persons) by 2016 and tests the predicted model with 20% unused data. And then, this study presents a construction site safety management process using the predicted model. The model and process developed in this paper are expected to contribute to the safety management of the construction site as a tool to prevent fatal accidents of construction workers.

Keywords: Demographic Characteristics, Machine Learning, Public Data, Safety Management, Prediction of fatal Accident

1. Introduction

1.1. Research background and purpose

When an industrial accident happens in Korea, accidents are reported to the Korea Workers' Compensation and Welfare Service (COMWEL). COMWEL determines whether an industrial accident is registered and collects information about the accident victims. This data is shared with MOEL, which makes up the industrial accident report. In this report, the cumulative value of survey items is presented, and it is reflected in the safety management with reference to the construction site. According to the report of MOEL, the number of industrial accidents had increased every year for six years from 2011 to 2016 (Figure 1), an annual average of 23,362 injured people, and 2,846 people died. This represents an annual average of 26.44 % of the total number of accident victims in the entire industry (MOEL, 2012; 2013; 2014; 2015; 2016; 2017; Choi et al. 2017). The result means that the statistical data did not influence the accident prevention of construction workers. It needs an easy way to use statistical data in the field. Therefore, the purpose of this paper is to propose a useful model to prevent fatal accidents in the field by utilizing industrial accident data collected from Korean public institutions.

Construction accidents are caused by physical causes (unsafe conditions, 10%), human causes (unsafe behavior, 88%), and indirect causes (environmental causes, 2%) (Heinrich et al. 1980). However, on-site training is conducted

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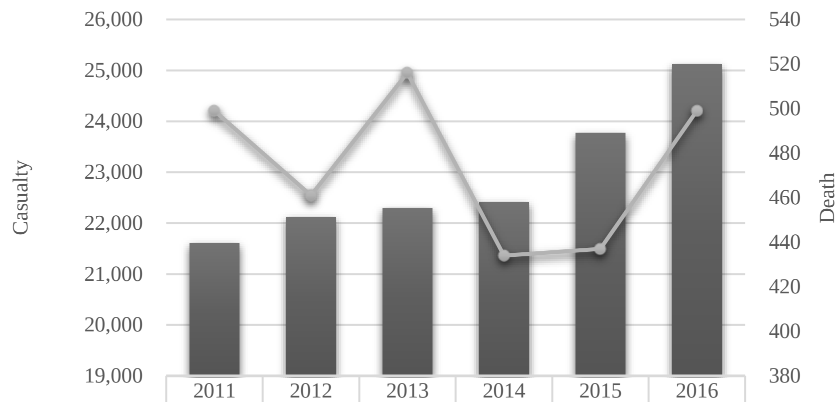
to eliminate unsafe behaviors that directly cause disasters, and there is no consideration of personal defects or personal characteristics, which are potential indirect causes of direct causes (Kim, 2008). This study classifies the workers who have a high probability of fatal accidents (death) by Machine-learning (Logistic regression model).



	2011	2012	2013	2014	2015	2016
Casualty	21,610	22,122	22,285	22,417	23,775	25,114
Death	499	461	516	434	437	499

Figure 1. Number of casualties and deaths by year (2011-2016)
(MOEL, 2012; 2013; 2014; 2015; 2016; 2017)

1.2. Research scope

The scope of the analysis was limited based on 2016 industrial accident data collected by MOEL based on age, sex, duration of career, accident date, project size, classification of casualty and death, and construction type. In 2016, industrial accidents consist of 25,114 casualties and 499 deaths.

1.3. Method

Machine learning about industrial accident information possessed by a public organization creates a predictive model that evaluates the risk of fatal accident when construction workers get to work. Depending on the degree of risk assessed, the safety manager can efficiently manage the workers based on the information of the day. First, collect construction workers' data from MOEL. Second, the collected data (age, sex, duration of career, project size, construction type, accident date) is pre-processed. Third, derive a regression equation that predicts fatal accidents (death) by machine-learning industrial accident data from a Logistic regression model.

2. Development of the prediction model for fatal accident

2.1. Data preprocessing

Data was received from MOEL through a public information portal (www.open.go.kr). It is personal information about the casualties and deaths of 2016. Values categorized in the supplied data require conversion for data analysis. For categorical data, the median was taken as the reference value. The unit of duration of career was converted into months.

2.2. Logistic regression model

D. R. Cox (1958) proposed a Logistic regression model. It is a statistical technique used to predict the likelihood of an event using a linear combination of independent variables as a probability model (Hosmer, D.W. et al. 2013). The

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Logistic regression is widely used in a variety of fields, including construction or social analysis. Wong (2004) used the Logistic regression model to formulate the Contract Execution Index for UK contractors. The goal of Logistic regression is the same as the goal of the general regression analysis. The relationship between the dependent variable and the independent variable is expressed as a linear combination function and used in future prediction models (Aram So et al. 2017). However, unlike linear regression analysis, Logistic regression can be seen as a kind of classification technique because the dependent variable includes categorical data and when the input data is given, the result of the data is divided into specific categories.

This study modeled it on the basis of a Logistic model because the data used in this paper included categorical data. Also, since it can be expressed in a simple line form, field managers can easily use the equation obtained based on this Machine learning method. The basic approach of Logistic regression is to use linear regression. The linear prediction function can be expressed as follows for a particular data term (Equation 1).

$$\mathrm{f}(i) = \beta_0 + \beta_{1\mathrm{x}_{1i}} + \cdots + \beta_m \mathrm{x}_{mi} \tag{1}$$

The Logistic model expression ensures that the dependent variable or result value is between the probability value [0, 1], as shown in Figure 2, regardless of the number of independent variables [-∞, ∞]. The result is classified as 0 or 1 according to the value 0.5.

In this paper, 80% of the total data was sampled during Machine learning, and it was verified as 20%. Since the data of the accident is 50 times more than the data of death, the data of death to predict the occurrence of a fatal accident is weight-learned.

2.2.1. Application of logistic regression model

First, the entire data was applied to the Logistic regression model (Table 1). As a result of the analysis, the age, duration of career, project size, whether it was Sunday or Thursday, and Architecture or Railway or track construction type or not influence on fatal accident. Second, the Logistic regression model was reapplied except for the data with insignificant impact. As a result, Table 2 was derived, and thus Equation 2 was determined. According to Table 2, the probability of occurrence of fatal accidents increases with old age, large project size, long duration of career, on Sunday, and in April. Also, the probability of occurrence in case of architecture project is lowered. A system using Equation 2 can easily classify workers who are likely to have a fatal accident.

Table 1. Apply the whole data to the Logistic regression model

		Estimate Std.	Error	z value	Pr(>|z|)	
(Intercept)		-4.406.E+00	4.329.E-01	-1.018.E+01	< 2e-16	***
Age		1.583.E-02	4.777.E-03	3.313.E+00	9.240.E-04	***
Woman		-3.528.E-01	3.410.E-01	-1.035.E+00	3.008.E-01	
Project size		1.159.E-03	1.639.E-04	7.072.E+00	1.530.E-12	***
Duration of career		7.867.E-03	1.805.E-03	4.357.E+00	1.320.E-05	***
Day of the week	Sunday	4.324.E-01	1.803.E-01	2.399.E+00	1.646.E-02	*
	Monday	-2.309.E-01	1.768.E-01	-1.306.E+00	1.917.E-01	
	Tuesday	-1.789.E-02	1.680.E-01	-1.060.E-01	9.152.E-01	
	Wednesday	9.085.E-03	1.680.E-01	5.400.E-02	9.569.E-01	
	Thursday	2.596.E-01	1.574.E-01	1.650.E+00	9.902.E-02	.
	Saturday	6.414.E-02	1.691.E-01	3.790.E-01	7.045.E-01	
Month	February	1.782.E-01	2.647.E-01	6.730.E-01	5.008.E-01	
	March	7.928.E-03	2.485.E-01	3.200.E-02	9.746.E-01	
	April	4.548.E-01	2.327.E-01	1.955.E+00	5.060.E-02	.
	May	-6.366.E-02	2.522.E-01	-2.520.E-01	8.008.E-01	
	June	4.328.E-02	2.420.E-01	1.790.E-01	8.581.E-01	
	July	2.004.E-01	2.385.E-01	8.400.E-01	4.008.E-01	
	August	-9.342.E-02	2.483.E-01	-3.760.E-01	7.068.E-01	
	September	8.261.E-02	2.500.E-01	3.300.E-01	7.411.E-01	
	October	2.036.E-02	2.430.E-01	8.400.E-02	9.332.E-01	
	November	-9.222.E-02	2.508.E-01	-3.680.E-01	7.131.E-01	
	December	-5.375.E-02	2.537.E-01	-2.120.E-01	8.322.E-01	
Const-ruction Type	Architecture	-7.539.E-01	2.939.E-01	-2.565.E+00	1.031.E-02	*
	Highway and subway	-1.043.E+01	5.354.E+02	-1.900.E-02	9.845.E-01	
	(High) dam	-1.015.E+01	3.086.E+02	-3.300.E-02	9.738.E-01	
	Machinery	1.717.E-01	3.846.E-01	4.460.E-01	6.553.E-01	
	Road	-1.426.E-01	1.069.E+00	-1.330.E-01	8.939.E-01	
	Hydropower Facility	-1.059.E+01	5.354.E+02	-2.000.E-02	9.842.E-01	
	Railway or track	1.557.E+00	8.172.E-01	1.906.E+00	5.669.E-02	.
	Others	-4.062.E-01	2.964.E-01	-1.371.E+00	1.705.E-01	

Table 2. Apply the data determined to be correlated to the Logistic regression model

	Estimate Std.	Error	z value	Pr(>|z|)	
(Intercept)	-4.644.E+00	3.013.E-01	-1.541.E+01	< 2e-16	***
Age	1.483.E-02	4.741.E-03	3.128.E+00	1.760.E-03	**
Project size	1.164.E-03	1.634.E-04	7.127.E+00	1.030.E-12	***
Duration of career	8.262.E-03	1.762.E-03	4.688.E+00	2.760.E-06	***
Sunday	4.071.E-01	1.443.E-01	2.821.E+00	4.790.E-03	**
April	4.256.E-01	1.402.E-01	-3.037.E+00	2.390.E-03	**
Architecture	-4.097.E-01	9.478.E-02	4.323.E+00	1.540.E-05	***

$$f(risk) = 1.483e^{-2}x_1 + 1.164e^{-3}x_2 + 8.262e^{-3}x_3 + 4.071e^{-1}x_4 + 4.256e^{-1}x_5 - 4.097e^{-1}x_6 - 4.644 \quad (2)$$

Note: χ_1 = Age, χ_2 = Project size, χ_3 = Duration of career, χ_4 = Day of the week (Sunday = 1, except for that = 0), χ_5 = Month (April = 1, except for that = 0), χ_6 = Construction type (Architecture = 1, except for that = 0) ※ Only one construction type must be selected.

2.2.2. Logistic regression model performance

In this paper, the performance is verified using k-fold cross validation (Kohavi, R., 1995). This is a method for increasing the statistical reliability of the classifier performance measurement in the machine learning field. The method is as follows. Divide the sample into groups of k. k-1 sets train the classifier and the other set to measure the performance of the classifier apply to the model. This process can be performed k different times, and the accuracy of the acquired k times can be averaged and defined as the performance of the classifier. The advantage of cross validation is that you can use most of the samples you have in Training. In the experiment, 5-fold crossover verification was conducted with 20 % of the data after learning from 80 % of the data.

The data in this paper are severely imbalanced, with the accident victim being 50 times more likely than the death victim. If the study calculates a typical error by creating a model that predicts all the predictors and all of the deaths fail, the study will have about 98 percent of performance. AUROC (Davis, J. et al. 2006) is a common means of measuring imbalance data performance in the field of machine learning. The closer to 1 is better the performance than the closer to 0.5. The result of AUROC measurements are shown in Figure 3. AUROC means the lower part of the graph line, and 0.6636 is simply a numerical value.

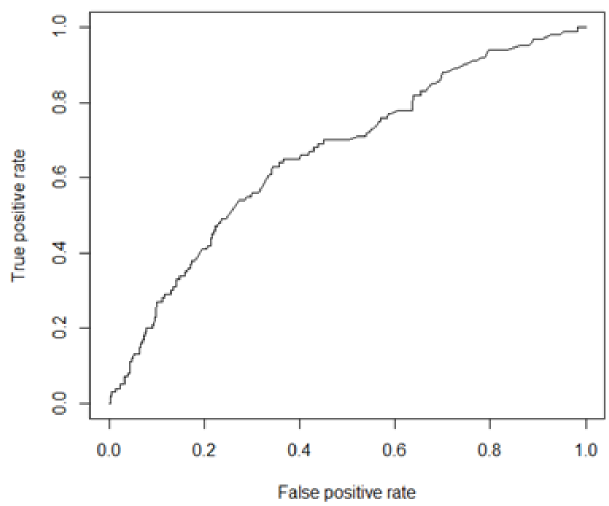

Figure 2. Result of AUROC measurement

3. Conclusion

This paper analyzed the data of 25,613 industrial accident victims of construction industry in Korea (25,114 accident casualties, 499 accident deaths). This study modeled the data based on a Logistic regression model because the data used in this paper included categorical data. For categorical data, the median was taken as the reference value. The unit of duration of career was converted into months. 80% of the total data were sampled and learned, and then 20% were verified. Since the data of casualties are 50 times more than the data of deaths, the weight of deaths is weight-learned in order to predict the occurrence of fatal accident in case of industrial accidents. All elements were analyzed and the Logistic regression model was applied again as a factor affecting the prediction. In this process, First, the sex was excluded. Second, the remaining days except Sunday and Thursday were excluded. Third, the month except April was excluded. Fourth, the construction types except for architecture and Railway or track were excluded. As a result, Equation 2 was derived. In the case of fatal accident, the probability of occurrence is higher when the age is higher, the duration of career is longer, the project size is larger, on Sunday, in April, and the probability of occurrence in case of architecture project is lowered. Finally, the 5-fold cross-validation of the AUROC model was 0.6636. Therefore, when the RFID, QR code, and biometric information are input to the device confirming the worker's work, the risk index is calculated and reported. Based on this index, the safety manager can classify and manage the daily risk groups efficiently, which is expected to prevent fatal accidents (Figure 4).

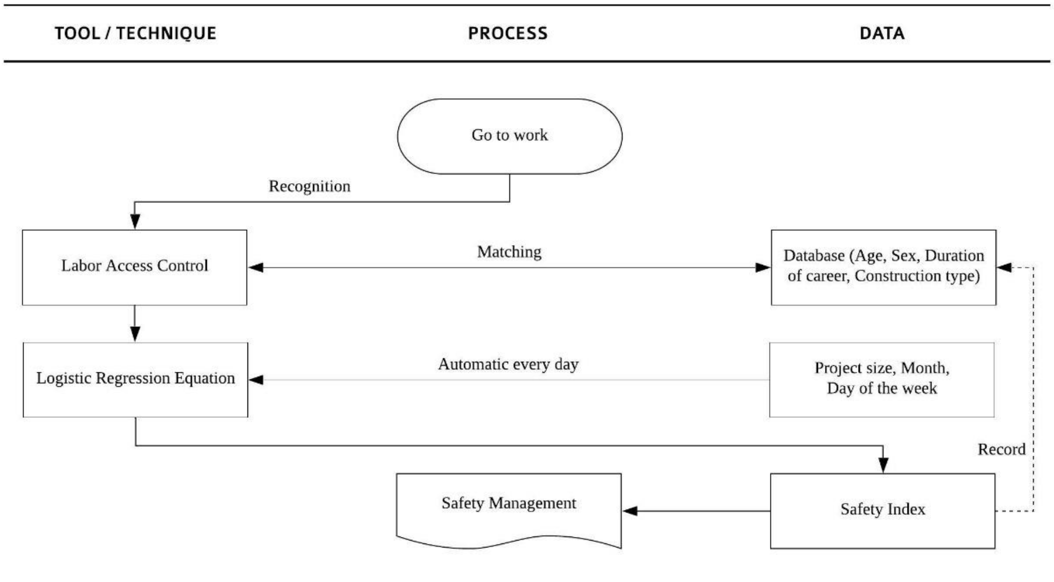

Figure 3. Safety management process using safety index

4. Limitation and Future Research

Currently, the data used in this paper is limited to 2016. By collecting yearly accident data and performing Logistic regression analysis, a result can obtain a higher performance than the Logistic regression equation derived from this paper. If data on general workers who are not hurt are collected in addition to those of the victims, it will be possible to carry out studies capable of predicting accidents as well as fatal accidents.

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Ecological and functional technical mortars with rubber

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Abstract

The finishing coatings of buildings, such as plasters and renders, are essential for the durability and sustainability of constructive solutions. Mortars provide constructive elements with protection and contribute significantly to thermal and acoustic comfort of the indoor environment. The development of ecological mortars with specific characteristics in response to the need for more sustainable construction represents an important challenge.
Considering the current quality requirements for mortar industries regarding technical specificities and the environment, it is fundamental that more recycled or natural raw materials, and material with lower environmental impact are introduced. Furthermore, the development of multifunctional mortars suited for different substrates ensures more versatility of the products. Looking to address these issues, this paper presents the development of mortars incorporating granulated rubber from used tires. This residue has been considered for the development of construction materials due to its lightness, elasticity and energy absorption capacity. It also provides improved thermal and acoustic behaviour.
For this purpose, 2 different mortar compositions with fine rubber granulate were analysed. Mechanical behaviour for different substrates was determined through compressive and flexural strength, dynamic elasticity modulus and adhesive strength. The hygrothermal behaviour of the mortars was also evaluated considering the results obtained for water vapour permeability, capillary absorption and thermal conductivity tests.
Very promising results were obtained in this study. These allow the framing of these mortars in the recent context of CE marking requirements for rendering and plastering mortars.

Keywords: Mortars; Multifunctionality; Recycling; Rubber Residues; Sustainability.

1. Introduction

The most recent environmental requirements have led to the research and development of ecological mortars incorporating by-products from several different industries. The processing of raw materials by industries generates tons of residues which are, most of the times, incinerated or deposited into landfills. These processes represent a considerable ecological footprint which can be reduced by the introduction of these residues in other production activities. In the construction market, several cementitious based materials such as bricks, concrete and mortars incorporating residues from glass, ceramics [1,2], cork [3-5], rubber, polymeric materials, among others [6] have emerged. In addition to ecological advantages, these by-products may also improve the hygrothermal [7-9], acoustic [10] and mechanical behaviour of concretes and mortars. The development of ecological and functional technical mortars for new constructions, or for rehabilitation purposes, requires the assessment of the feasibility of the incorporation of by-products, considering their regional and national availability.

The use of recycled rubber from tires may be done through 3 different ways: reutilization, recycling or energy recovery. Any of these allow the reduction of the environmental impact related to the extension life-cycle of this product. The incorporation of rubber residues in mortars might be included in the first or second ways that is reutilization or recycling.

There are several studies dedicated to the development of mortars with rubber from tires. The use of this material as a partial replacement of natural aggregates is very well documented and it is supported by experimental research [11-16]. This residue has become more accepted in construction due to its intrinsic characteristics, such as lightness (lower density), higher elasticity and higher energy absorption. Besides, it provides improved thermal and acoustic behaviour. The percentage of rubber and particles sizes have major influence on the properties of mortars, in fresh or hardened state. A synthesis of the influence that incorporating rubber has on several relevant properties is presented in Table 1.

Table 1: Effect of replacing of natural aggregate with rubber.

Property	Effect of replacing natural aggregate with rubber
Water absorption	Non-consensual data
Bulk density	Decreases with the increase of the % of rubber
Workability	Decreases with the increase of the % of rubber Decreases with the growth of the particles size
Compressive Strength	Decreases with the increase of the % of rubber (the influence of particles size is not clear)
Voids percentage	Increases with the increase of the % of rubber
Flexural strength	Decreases with the increase of the % of rubber (the influence of particles size is negligible)
Thermal insulation	Increases with the increase of the % of rubber

Aggregates from rubber tires might be obtained in two ways: mechanical crushing or cryogenic crushing. In the mechanical process, rubber is fragmented using several crushers and mills. Steel is separated magnetically and the textiles are separated from density differences. After that, rubber granules are separated in different ranges, according to the size of the particles, by sieving with mesh. In the cryogenic process, liquid nitrogen is used to freeze the rubber, which allows its fragmentation and, consequently, the production of fine rubber aggregate. Initially, the rubber is crushed and then transported to a cryogenic tunnel where the nitrogen input temperature is approximately (-192)ºC, and the output temperature is about (-80)ºC. After crossing the cryogenic tunnel and the pneumatic hammers, the steel and textiles from the tires are separated from the rubber by a magnetic apparatus and with suction, respectively.

Some of the most interesting properties of rubber aggregates are:

- Non-floatable or with reduced floatability;
- Stability over time;
- Very good elastic response per unit mass;
- Meets the PAH’s test (polycyclic aromatic carbonates harmlessness / toxicology);
- Safe for health according to OSHA OMB N.º 1218-0072;
- Meets the DIN V 18035-7 related to the emission of leaching of heavy metals and organic pollutants;
- Does not release carbon black (does not dirty the skin or clothes);
- Compaction, friction and abrasion resistant;
- Almost non smelling;
- Resistant to UV radiation;
- Resistant to weather.

The present study was framed within the “EFTM - Functional Technical Mortars” founded project, which focused on developing an ecological and multifunctional mortar incorporating rubber residues with ability to be applied onto different substrates. Two different compositions were analysed and compared in what concerns to their workability, flexural and compressive strength, dynamic elasticity modulus, adhesive strength, water vapour permeability, water absorption by capillary action, bulk density and thermal conductivity. The results were also compared to the requirements established by the specification for mortar for rendering and plastering, EN 998-1.

2. Experimental program

2.1. Mortar characterization

After some preliminary laboratory tests with different proportions, two different mortars with rubber granulates were selected and characterized. The two selected mixtures were the ones which presented, after an empiric analysis based on visual inspection, workability and earliest shrinkage.

The rubber dust used in the mixtures was obtained by cryogenic processes, which allowed the maintenance of its most interesting characteristics. The cryogenic cooling of the polymers from rubber, by means of liquid nitrogen followed by grinding with a high impact hammer mill (without friction, shear strain or abrasion on the rubber surface), provides grains with cubicoid morphology, plain surfaces and with almost no pores. This process does not chemically or thermally degrade the molecular chains of the rubber polymers, nor its vulcanization condition. Its elastic properties (impact absorption; elastic recovery) do not change over time. The durability additions of the tire rubber (antioxidants, UV protection, stabilizers and others) maintain over time, providing high resistance to environmental ageing.

The size of the particles of the rubber dust, exhibited in Figure 1, varies between 0,18 mm and 0,6 mm. The particles present a density of 0,454 g/cm^3.

Fig. 1. Rubber dust

Rubber dust mortars were produced with about 30%, in mass, of binder (Portland cement), 12% of calcium carbonate, and sand and rubber dust as aggregates. Several additions were also used (water repellents, stabilizers, stiffeners, air introducers, and others), representing 2,8% of the mixture, in mass.

Table 2 presents all of the characterization tests performed and the respective standards.

The two mortars were designated as Primerubber R20 and Primerubber R35. The amount of water used was determined considering an adequate workability: for Primerubber R20, 220 ml/kg dry mixture was used, and for Primerubber R35, 270 ml/kg dry mixture was used. Primerubber R20 presented a Flow value of 164 mm, and Primerubber R35 of 166 mm.

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Table 2: Properties determined for the mortars with rubber.

Properties	Standard procedures
Fresh mortar	
Workability (mm)	Determination of consistence of fresh mortar (by flow table) (EN 1015-3:1999; EN 1015-3:1999/A1:2004; EN 1015-3:1999/A2:2006)
Hardened mortar – mechanical characterization	
Flexural strength - R_F (N/mm^2) Compressive strength - R_C (N/mm^2)	Determination of flexural and compressive strength of hardened mortar (EN 1015-11:1999; EN 1015-11:1999/A1:2006)
Dynamic Modulus of Elasticity – Ed_L (MPa)	Determination of the dynamic modulus of elasticity (by measuring the fundamental resonance frequency) (based on NP EN 14146:2006 - Method 5.2, for natural stone)
Adhesive strength – f_u (N/mm^2)	Determination of adhesive strength of hardened rendering and plastering mortars on substrates (EN 1015-12:2000)
Hardened mortar – physical characterization	
Water vapour permeability coefficient - μ (-)	Determination of water vapour permeability of hardened rendering and plastering mortars (NP EN 1015-19:2008)
Dry bulk density (kg/m^3)	Determination of dry bulk density of hardened mortar (EN 1015-10:1999; EN 1015-10:1999/A1:2006)
Water absorption coefficient - C_m (kg/(m^2.min$^{0.5}$))	Determination of water absorption coefficient due to capillary action of hardened mortar (EN 1015-18:2002)
Thermal conductivity 10ºC [W/(m.ºC)] Thermal conductivity - EN 1745 - $\lambda_{23,dry,mat}$ [W/(m.K)]	Determination of thermal resistance by means of guarded hot plate and heat flow meter methods (EN 12664:2001; ISO 8302:1991)

2.2. Mechanical characterization

Table 3 presents the results obtained for the mechanical characterization of the mortars with rubber, including standard deviation and variation coefficient.

Table 3: Test results for mechanical characterization of mortars with rubber.

	Primerubber R20	Primerubber R35
R_F (N/mm^2)	**2,3**	**1,4**
StD	0,18	0,02
C.V. (%)	0,08	0,02
R_C (N/mm^2)	**4,0**	**1,7**
StD	0,16	0,02
C.V. (%)	0,04	0,01
Ed_L [MPa]	**2179**	**692**
StD	101,8	2,9
C.V. (%)	4,7	0,4

It was observed that Primerubber R20 presents higher flexural and compressive strength and, consequently, higher elasticity modulus.

Concerning compressive strength, according to EN 998-1 specification standard for rendering and plastering mortars, Primerubber R20 is classified as CS II and Primerubber R35 as CS I or CS II (close to the lower limit of CS II class).

Since the results obtained for Primerubber R20 were more satisfying, and for logistical reasons, the adhesive strength tests were performed only for this mixture. Adhesive strength tests were performed over different substrates, with or without pre-coating, when necessary. The results are presented in Table 4.

Table 4: Test results for adhesive strength of Primerubber R20 mortar.

Substrate		f_u (N/mm^2)	StD (N/mm^2)	C.V. (%)	Fracture
Perforated ceramic masonry unit	Direct application	0,19	0,04	20,7	Pattern B
Perforated concrete masonry unit	Direct application	0,13	0,10	74,0	Pattern B
Solid concrete	Direct application	0,27	0,03	9,4	Pattern B
	With primer coat	0,24	0,05	22,0	Pattern B
Porcelain stoneware tile	Direct application	0,17	0,03	18,2	Pattern B
	With primer coat	0,22	0,04	16,6	Pattern B
Plasterboard	Direct application	0,09	0,03	31,6	Pattern A
	With primer coat	0,17	0,04	24,5	Pattern B
Birch plywood	Direct application	0,12	0,02	18,8	Pattern C
	With primer coat	0,21	0,04	17,1	Pattern B
MDF Standard (medium density wood fibreboard)	Direct application	0,09	0,02	20,6	Pattern B
	With primer coat	0,09	0,02	20,6	Pattern B
Certis® (cement bonded particleboard)	Direct application	0,18	0,05	29,7	Pattern B
OSB3 (oriented strand board – wood based)	Direct application	0,03	0,01	30,7	Pattern A
ICB (expanded insulation cork board)	Direct application	0,12	0,02	15,9	Pattern C
EPS (expanded polystyrene insulation board)	Direct application	0,11	0,02	20,7	Pattern C

In general, it can be said that Primerubber R20 develops good cohesion between several kinds of substrates, including wood-based ones. Lowest values of adhesive strength were obtained for plasterboard without primer, MDF with or without primer and OSB without primer. For those, plasterboard and OSB directly applied onto the substrates presented a fracture pattern type A, adhesion fracture, which means that fracture occurred at the interface between the mortar and substrate. In the specific case of plasterboard, the use of a primer coating solved this issue. For MDF, even with primer, the adhesive strength kept lower, with a type B fracture pattern in both cases, which corresponds to the cohesive fracture occurring in the mortar itself.

Overall, Primerubber R20 presented a type B fracture pattern, except for ICB and EPS supports, in which case the fracture occurred in the substrate material. This behaviour was expected since these substrates have lower mechanical strength.

2.3. Physical characterization

Table 5 presents the results obtained for the physical characterization of the mortars with rubber, and includes the standard deviation and variation coefficient.

Table 5: Test results for physical characterization of rubber mortars.

	Primerubber R20	**Primerubber R35**
Wvp coefficient, μ (-)	**11,1**	**7,2**
StD	0,7	0,2
C.V. (%)	6,3	3,2
Dry bulk density (kg/m^3)	**1201**	**955**
StD	0,6	2,0
C.V. (%)	0,1	0,2
C (kg/(m^2.min$^{0.5}$))	**0,20**	**0,10**
StD	0,00	0,00
C.V. (%)	0,0	0,0
$\lambda_{23,dry,mat}$ (W/(m.K))	**0,283**	**0,202**
StD	0,008	0,002
C.V. (%)	3,0	1,0
$\lambda_{23,dry,mat}$ (W/(m.K)) EN 1745	0,341	0,256

Primerubber R20 presented higher water vapour permeability coefficient and water absorption by capillary action, higher density and higher thermal conductivity. Considering these results, rubber granulates might increase the amount of smaller pores, which lead to higher water vapour permeability and water absorption by capillary action. As expected, the increase of rubber in the composition of the mortar decreased its density, as rubber is lighter than natural sand. Also, considering the thermal behaviour of rubber, it was confirmed that the increase of the percentage of rubber decreases thermal conductivity.

Concerning the EN 998-1 specification standard, both Primerubber R20 and Primerubber R35 may be classified as W_C2, as their capillary coefficient is equal to or less than 0,2 kg/(m^2.min$^{0.5}$). Neither of the mortars can be classified as thermal insulating mortar. However, Primerubber R35 obtained a value close to a T2 classification (≤ 0,2 W/(m.K)).

2.4. Mortars classification

Considering the parameters evaluated with the experimental campaign, it is possible to frame the studied mortars in the context of the specification standard for mortars for rendering and plastering, EN 998-1.

By analysing the requirements presented in Table 2 of the referred standard set for hardened mortars, it is confirmed that both mortars meet all the requirements for classification as GP, general purpose mortars, CR, coloured rendering mortars, and also LW, lightweight mortars, as their density is inferior to 1300 kg/m^3.

To be declared as thermal insulating mortars, T2, products must have a thermal conductivity equal to or less than 0,2 W/(m.K). Primerubber R35 is very close to this limit, and, with a water vapour permeability coefficient under 15, also complies with the requirement for water vapour permeability.

For the other types of mortars, the characterization performed was not sufficient in order to define the mortars as OC, one-coat rendering mortar, or as R, renovation mortars.

3. Conclusions

In the framework of the project "EFTM - Ecological and Functional Technical Mortars", which aimed for the development of ecological mortars with improved characteristics and ability for application onto several substrates and under different conditions, mortars incorporating recycled rubber granulates were produced and characterized. Two different compositions were developed and characterized in laboratory conditions, in the fresh and hardened state, from the mechanical and physical point of view. The obtained results enabled, not only the evaluation of the overall behaviour of the mortars, but also their framing within the requirements set by the specification standard for CE marking for mortars for rendering and plastering.

It was observed that the global performance of rubber mortars is very satisfying. However, Primerubber R20 presented better mechanical behaviour and Primerubber R35 better physical behaviour. The adhesive strength of Primerubber R20 stands out, as this mortar presents high compatibility with different substrates. This aspect reinforces the multi-functionality, sustainability and versatility intended for these mortars.

However, given the results obtained, it was considered that these compositions need to be improved, so as to establish a compromise between the improved mechanical behaviour of Primerubber R20 and the improved physical behaviour of Primerubber R35. Also, an extended characterization is being performed in order to understand other physical properties, such as acoustic behaviour and durability of the mortars when exposed to accelerated ageing conditions and “in situ” conditions.

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Energetic analysis of complex modernizations of educational buildings

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Abstract

In this paper, the complex modernizations of existing educational buildings are examined from energetic aspect. A case study based research was conducted between 2010 and 2017 with the involvement of architect student groups. The selected buildings are architecturally valuable secondary schools in Győr (Hungary) built in 1950-70. Firstly, the present conditions of the buildings were recorded in plans and in experts' reports. Secondly, 18 complex modernization designs were developed on the 6 buildings in order to offer complex solutions to the existing problems. The analyzing and planning processes were done with a holistic approach. The main motive of building modernization is usually to improve energy efficiency, therefore energy performance of buildings were examined on scientific level according to the Hungarian regulations in the second part of the research. Detailed energy calculations were made in the present and modernized conditions of the school buildings based on design proposals. In this way, the effect and efficiency of each modernizing measure could be analyzed revealing the omitted possibilities of the plans. Main conclusion of the evaluation was that the existing buildings could not fulfil the new, stricter energetic requirements if they had been renovated with usual methods. Based on the lessons, a general action plan was formulated with 12 measures in logical order, which can be applicable on any buildings having similar characteristics to the examined ones. In this way, these can be renovated according to the expectations of cost-optimal or nearly-zero-energy buildings, as well. Suitability of the general action plan was tested with energetic calculations on the studied school buildings. The energetic analysis revealed that the suggested general action plan could be effectively applicable to the modernization of existing educational buildings.

Keywords: building renovation; complex modernization; educational buildings; energetic analysis; energy performance of buildings

1. Introduction

During the past two decades, our building construction practice has significantly changed. One of the most important modifying effects is our new approach to the energy performance of buildings, especially in the European Union. The EU is already addressing energy efficiency as a priority issue, not only because it is aware of the seriousness of the global situation, but also because its territory is relatively poor in energy sources, so the dependence of countries on energy imports is high. "Energy policy for Europe" has been steadily developing since the years 2000. Energy strategies were established with concrete targets for 2020, 2030, and 2050 [1-3]. The 2010/31/EU Energy Performance of Buildings Directive [4] and some background studies [5, 6] introduced the notions of cost-optimized and nearly-zero-energy buildings. These studies investigated the construction and operation costs of new buildings in a 30-year long period searching for the cost optimal situation. According to the directive, EU states constituted the national regulations with quantitative requirements in the past few years. In Hungary, this actual regulation is the several times modified 7/2006. TNM Decree [7]. The more serious energetic requirements written in the decree must be implemented from 2018 in the case of cost-optimized, and from 2021 in the case of nearly-zero-energy buildings.

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In Hungary, 40% of the total energy consumption is used in our buildings. This rate has practically remained unchanged over the past ten years and corresponds to the rate observed in EU countries with similar geographic conditions [8]. The absolute amount of building related energy use can be decreased when new buildings are built in an energy-efficient way, and when existing buildings are renovated energetically. Energy strategies and the background studies generally focus on the new buildings, particularly on the new residential ones, though energetic modernization of existing buildings has also great potential, especially in case of public buildings. The replacement of public buildings with newly built, energy-efficient ones is even smaller than the renewal of the residential building stock, so here almost the only energy consumption reduction can be expected through building renovations. Public buildings are the 12% of the whole building stock in the EU, and 17% of GDP is spent for public building related expenditures. Among the public buildings, the educational buildings are represented in the largest number, in Hungary this rate is 42% [9]. Based on these, it would be reasonable to place significant emphasis on government-initiated renovation of the existing public buildings, starting with the largest stock, on educational buildings.

The energetic modernization of existing educational buildings raises a number of issues in the light of the new cost-optimized and nearly-zero-energy requirements. For example:

- Can educational buildings be modernized according to cost-optimized or nearly-zero-energy expectations?
- What kinds of energy savings are available in an educational building?
- Is the 25% renewable energy ratio available for a renovated school building?
- Is it possible to improve the energy quality of schools better with the right choice of modernization measures?
- How could educational buildings demonstrate the energy awareness for students, teachers, and society?

2. Methods

The research into the complex modernization of educational buildings described in this article was conducted in the Széchenyi István University 2010-2017 with the involvement of architect students. The initial goal was that students gain experiences in the multi-criteria status analysis and complex modernization of existing buildings from the second half of 20th century in teamwork. Educational buildings of Győr were obviously suitable for the investigation. During that period, 6 different secondary schools were examined by different student groups with the same methodology as case studies. Students could practice the on-site inspection, documentation from archives, making expert opinions, complex modernization design from program creation to detail processing. To the 6 buildings, 18 different modernization plans were developed. From the surveys and modernization plans, technical reports were edited, which are now online accessible documents, referencing to the all utilized sources and their authors [10-15].

Meanwhile, it became clear that the students' works are worth for further consideration and the detailed analysis. Therefore, the university project was converted into a personal research project in which the energetic performances of the school buildings were investigated as case studies. Firstly, characteristics of the buildings were described in order to answer the question: Do the selected buildings belong to one characteristic group? After that, their energetic feature data were determined according to the Hungarian regulations and calculation methods [7], which are harmonized with the EU standards. Calculations were made with the Auricon Energetic software in the legal and software environment in July 2017. Buildings were examined in several conditions (in current state, according to modernizations or action plans), but the boundary conditions and the applied simple or detailed methods were the same in each calculation, so the comparability of the results was assured.

3. Designing complex modernizations of educational buildings in Győr

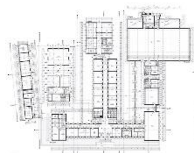
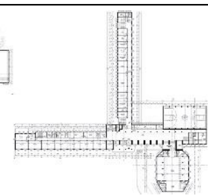
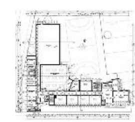
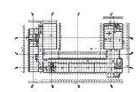
3.1. Selection of buildings

We intend to issue university semester assignments in which the systematic status analysis of existing buildings and the development of renovation and expansion plans can be practiced by students. For this, we have been looking for local buildings, which offer a sufficiently complex task, and whose future renewal is a task ahead. Thus, the opinions and suggestions developed can even contribute to the real modernizations of buildings, what motivates students to work properly on the one hand and institutions to support our work on the other hand. The above mentioned aspects are particularly true for schools, most of them have problems in each topics to be studied.

In Győr there are about 45 kindergartens, 30 primary and 30 secondary schools with often changing institutional and building backgrounds. The age of the buildings has naturally a large variance, there are hundreds of years old and quite new buildings, and we have to mention the partially or completely renovated, possibly enlarged buildings as well

[16]. The buildings of the 1950s and 1960s were chosen because these were interesting and valuable ones from architectural aspects, and from constructional point of view they were born in a particularly exciting era when industrialized technologies replaced the traditional ones. The six chosen educational buildings are presented in Table 1, where some identifying data, typical images, and ground floor plans are also visible.

Table 1. Parallel presentation of the studied buildings.

Assignment year	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16
School name shortly	Hild József Secondary School of Construction	Bercsényi Miklós Secondary School of Transport and Sport	Lukács Sándor Secondary School of Mechatronics and Mechanics	Baross Gábor Secondary School of Economics and Management	Dance & Fine Arts Primary and Secondary School of Győr	Szabóky Adolf Vocational School
A typical image						
Ground floor plan, same scale						
Architects	Fátay T, Eördögh É, Sebők T.	Cserhalmy J, Winkler G, Mikóczi T; Czeglédi	Rimanóczy Gy.	Hegedűs E, Mikóczi T, Lados P, Németh Gy	Harmati J. Papp L, Ambrus Z, Wyberál L.	Vidra A. Németh Gy.
Designing and construction	1956-58; 1958-62.	1950; 1955-56.	1950; 1951-53.	1961-62; 1962-64.	1962; 1963.	1967; 1969.
Expansion and/or restructuring	1973: new wing; 1991: gym	1969: workshop; 1975: gym; 1984: classrooms; 1994: garages	1961: gym, by original plans	1986: new block; 1997: great hall; 1999: new storey	1988: ballet halls	2004, 2006: small internal transformations
Total floor area	3 324 m^2	8 810 m^2	11 668 m^2	4 226 m^2	3 615 m^2	3 001 m^2
Volume	11 469 m^3	32 978 m^3	42 119 m^3	16 828 m^3	12 882 m^3	10 003 m^3

3.2. Multi-criteria status analysis

For complex status analysis of existing school buildings, the assessment and recording of the current state of buildings are indispensable. Students made 1:200 scale recording plans compiled the original designs from the city and school archives and actualized with the modifications noticed during the on-site inspections. Information was collected on the operating experiences drawing our attention to architectural, functional, constructional and service deficiencies of buildings. The student groups reviewed the buildings, expert opinions were made, presented and discussed together. The method of multi-criteria status analysis has progressively refined over the period, covering the following areas, according to the specific literature:

- exploring architectural values, making value inventories;
- functional compliance according to the regulations and standards of secondary education buildings;
- accessible and universal use based on existing regulations and design aids;
- identification of building structures, condition survey using visual inspection and thermal images;
- energy performance based on current regulations, with detailed energy calculations helped with software and on the general literature of the subject;
- building acoustics: soundproofing and noise protection, room acoustics;
- fire protection of buildings based on existing regulations and educational materials.

In the status analysis, 50-60 year old buildings were examined according to the current expectations. Therefore, it is almost natural that buildings do not conform in all respects to the recent technical requirements. These, for example in the building energetics and fire protection, have changed considerably in the past few years, but there are many changes in functionality as well, considering the necessity of accessibility or reviewing existing standards for schools.

3.3. Modernization designs

Comparison of recent requirements and the features of existing educational buildings helped the student groups with the definition of their own design programs for complex modernizations. In the programs, the different problems were represented with different emphases, in this way groups could develop different complex solutions. The stressed problems in the design processes have changed from year to year according to the particular requirements of the buildings and to the students' preliminary qualifications. Therefore, other and other aspects were in the focus of interest in the certain groups' work, such as the education as function, accessibility, preservation of architectural values, increased energy awareness, or implementation of passive house components. Each design proposal contains valuable ideas, which can draw the attention to existing problems and give some ideas to solve them.

Altogether 18 different complex modernization designs were developed to the 6 schools over the period. This means on average three plans per building. Within the framework of this article, only a small part of the voluminous materials of the design proposals may be presented (Table 2), therefore detailed research reports [10-15] were prepared to each school building, in which the status survey, the main results of multi-criteria analysis, and the different complex modernization proposals were also published with several useful and interesting data.

Table 2. Research reports and an overview of alternative modernization proposals

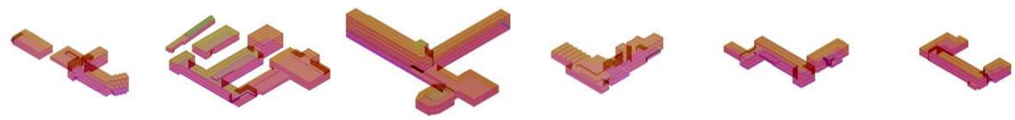
School name	Hild	Bercsényi	Lukács	Baross	Dance&Art	Szabóky
Front-page of research report						
Reference, pages	[10] 50 pages	[11] 50 pages	[12] 80 pages	[13] 62 pages	[14] 60 pages	[15] 50 pages
Content	3 record, 3 proposal	1 record, 2 proposal	1 record, 3 proposal	1 record, 4 proposal	1 record, 3 proposal	1 record, 3 proposal
A typical image of "A" proposal						
A typical image of "B" proposal						
A typical image of "C" proposal						

4. Energetic analysis of designed complex modernizations

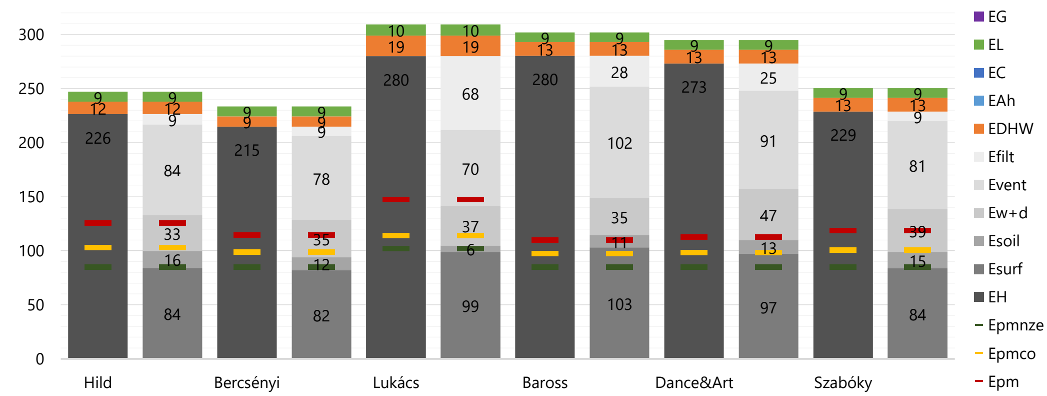
4.1. Energetic analysis in the present conditions

Although the student groups were motivated to design complex modernizations taking into account almost all aspects, we were aware that, unfortunately, modernizations are often incomplete in real life. "It is difficult and meaningless to separate purely technical, energetic or sustainability-based interventions, however in most cases this happens." [17] It is possible to examine each modernization objectives, to what extent it contributes to improving the sustainability of the building that is to what extent they are beneficial from the environmental, social, and economic aspect. In general, it can be stated that those modernization goals have a greater chance of realization, which are proven economical. Experience shows that the main motivation of building renovations is at present the desire for energy saving [18]. Investigating the energy consumption of buildings is usually a priority in preparing decisions on modernization, therefore energy indicators of the six building complexes were examined with detailed energetic calculations, at first in the current state. Main results of the calculations are presented in Table 3.

Table 3. The energy indicators of the six educational buildings in current state

School name	Hild	Bercsényi	Lukács	Baross	Dance&Art	Szabóky
Spatial relations, heated spaces and cooling surfaces of buildings, axonometries, in scale						

Energy demand of:
E_H: heating, in this:
E_{surf}: cooling surf.
E_{soil}: soil contact
E_{w+d}: windows
E_{vent}: ventilation
E_{filt}: filtration
E_{DHW}: hot water
E_{Ah}: air handling
E_C: cooling
E_L: lighting
E_G: energy gain
Requirements:
E_{pmnze}: nearly zero
E_{pmco}: cost-optimal
E_{pm}: general, old



	Hild	Bercsényi	Lukács	Baross	Dance&Art	Szabóky
Heat loss factor [q]	0.446 W/m³K	0.456 W/m³K	0.497 W/m³K	0.406 W/m³K	0.481 W/m³K	0.459 W/m³K
Energy perf. [E_p]	246.917 kWh/m²a	233.308 kWh/m²a	309.304 kWh/m²a	301.858 kWh/m²a	294.791 kWh/m²a	250.407 kWh/m²a
Renewable energy	5.779%	6.355%	3.624%	5.107%	5.397%	7.374%
Energy class	290%; GG	274%; GG	305%; GG	355%; HH	347%; HH	295%; GG

In Table 3, the energy indicators of the six educational buildings are visible with the dimensions of the buildings. Red color signs that the indicator could not fulfil the concerning requirements. In the graph, each building has two columns. In the first one, the main components of the overall primary energy performance are included: heating, air handling, cooling, domestic hot water, lighting and energy gains. In the second one energy needs of heating are shared in proportion of heat losses: building boundary structures apart from doors, windows and soil contact structures, ventilation and filtration. Overall, it can be stated that the average of the energy performance of the currently partially renovated buildings is 272.76 kWh/m²a (standard deviation: 29.98) which represents 311% of the reference value (standard deviation: 30), so their average energy class is HH or “weak”.

4.2. Energetic analysis according to the designed modernizations

In the next step, the energy indicators of the modernized buildings had to be determined according to the 18 proposals. In this process, it was only partially possible to rely on the students’ energy calculations because they were not prepared with a uniform methodology. Therefore, new calculations had to be made for all plans in accordance with current rules, with a consistent approach. The students’ task was not only to renovate existing structures, but they had to develop complex proposals based on the results of multi-criteria analysis, therefore the buildings had been substantially modified or enlarged in several versions, or just the alignment of the thermal envelope were adjusted. The modifications are illustrated in the figures of Table 4, where the main results of calculations are also presented.

Summarizing the results, we can see that, although all 18 modernization plans significantly reduced the specific primary energy use of the schools, none of them could be fully met with the complex requirements of nearly-zero-energy buildings. The same can be said for the cost-optimized requirements, which should be applied for the renovation of an existing building under the current regulation. Overall, it can be concluded that the average of the energy performance of the complex modernized buildings is 127.40 kWh/m²a (stand. dev: 18.84) which represents 146% of the reference value (stand. dev: 27), so their average energy class is DD or “approaching up-to-date”.

The result of the energy calculations of the complex modernized buildings showed that buildings could not have been renovated according to the new cost-optimized or nearly-zero-energy building requirements with the usual design methods and solutions of the current technical practice. For the preparation of renovations careful architectural, constructional and building service engineering design is needed with the application of effective new technologies.

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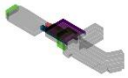
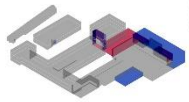
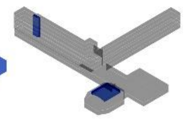
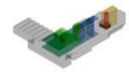
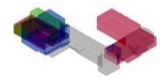
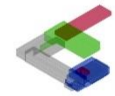
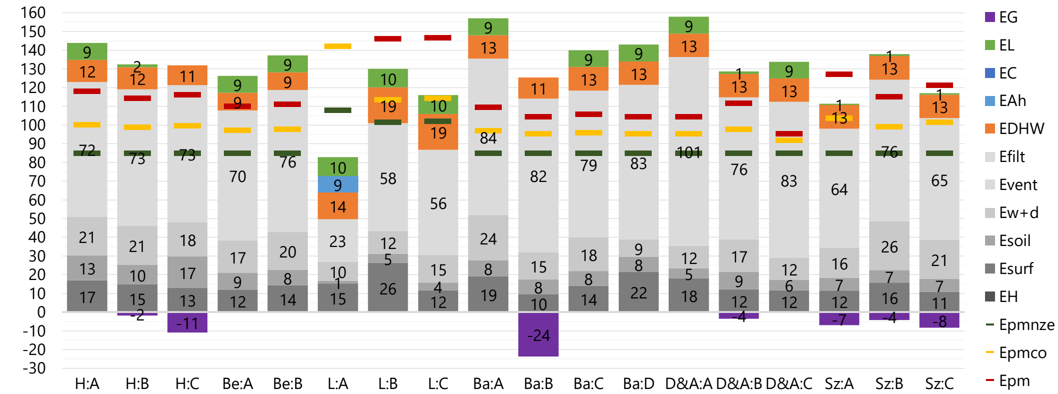
Table 4. The energy indicators of the buildings according to the complex modernization proposals

School name	Hild			Bercsényi			Lukács			Baross				Dance&Art			Szabóky		
Changes in spatial relations, heated spaces and cooling surfaces of buildings in plans, axonometries																			
Versions	H:A	H:B	H:C	Be:A	Be:B	L:A	L:B	L:C		Ba:A	Ba:B	Ba:C	Ba:D	T:A	T:B	T:C	Sz:A	Sz:B	Sz:C
Energy demand of: E_H: heating, in this: E_{surf}: cooling surf. E_{soil}: soil contact E_{w+d}: windows E_{vent}: ventilation E_{filt}: filtration E_{DHW}: hot water E_{Ah}: air handling E_C: cooling E_L: lighting E_G: energy gain Requirements: E_{pmnze}: nearly zero E_{pmco}: cost-optimal E_{pm}: general, old																			
H. l. f. [q] W/m³K	0.176	0.145	0.167	0.129	0.130	0.114	0.162	0.110		0.141	0.083	0.109	0.108	0.077	0.118	0.078	0.111	0.131	0.113
E. p. [E_p] kWh/m²a	144	131	121	126	137	83	130	116		157	102	140	143	158	125	134	104	134	109
Renewable energy	8.2%	12.7%	10.9%	9.3%	10.0%	16.5%	7.4%	8.7%		10.0%	14.0%	10.0%	8.0%	7.1%	10.9%	6.9%	15.8%	15.7%	18.7%
Energy class	169% EE	154% DD	142% DD	148% DD	161% EE	77% AA	128% CC	114% CC		185% EE	120% CC	165% EE	168% EE	186% EE	147% DD	157% DD	123% CC	157% DD	128% CC

5. Action plan to make energy modernization of educational buildings more efficient

5.1. Action plan: modernization steps in logical order

A revision were prepared in which the partial results of the energy calculations were compared in the existing and the modernized state of the buildings. Following the sequence of calculation lessons were collected from the energy aspects of the design process. Based on the lessons, general proposals were formulated for the efficient design of energy modernization of school buildings. After that, concrete proposals were elaborated for the renovations of the six building complexes in consideration of the architectural and environmental characteristics of them, so the applicability of the general proposals or the action plan was tested on all six buildings.

The elements of the general building modernization action plan in the logical order of the application: (1) Definition and rationalization of the position of the thermal envelope. (2) Subsequent heat insulation of the heated volume boundary structures, preferably in accordance with the cost-optimized requirements, taking into account the technical state of the structures and the architectural values. (3) Revision of the thermal bridges in the heated volume boundary structures. (4) Heat insulation of the soil-contact structures in a rational manner, taking into account the technical state of the structures and the architectural values. (5) Replacement of doors and windows no longer meeting the requirements for heat insulation and/or airtightness. (6) Elimination of leaks, ensuring general air tightness. (7) Modernization of ventilation according to functional demands to reduce the heat loss of air exchange by the installation of decentralized ventilation systems with heat recovery, preferably in the whole building with intermittent operation. (8) Optimization of direct radiation heat gains with the tools of appropriate glazing, window division and shielding, taking into account the risk of overheating in the summer. (9) Modernization of the heating system, supporting with renewable energies. Exploration of the possibilities of geothermal heat production according to the characteristics of the building and its surroundings. (10) Modernization of the domestic hot water system, supporting with renewable energies. Connection to the heating system if possible and reasonable. (11) Modernization of the lighting, supporting with renewable energies. (12) Installing solar photovoltaic panels on roofs to supply the building service systems and other electrical consumers, according to the characteristics of the building and its surroundings.

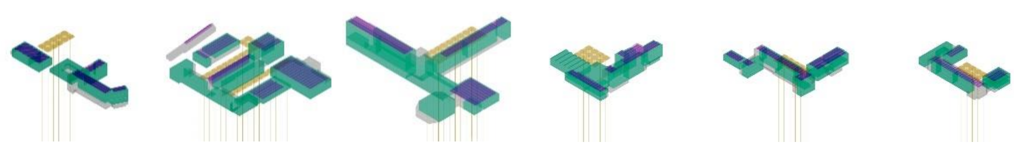
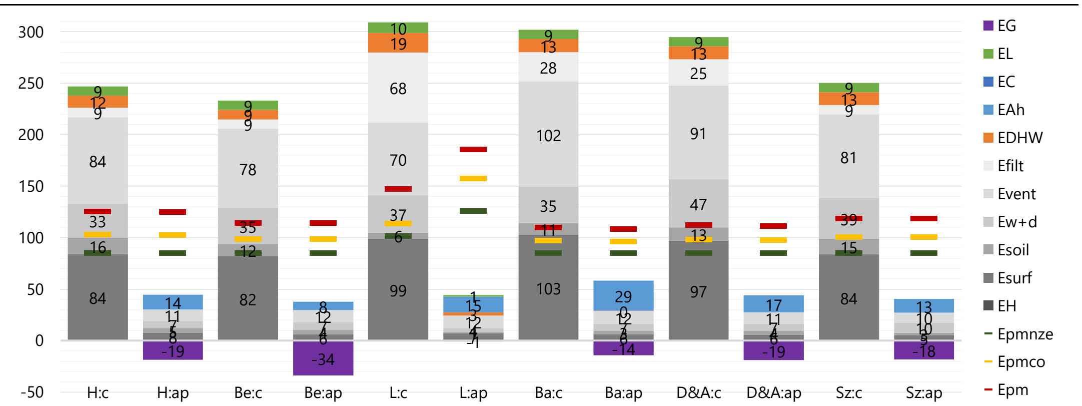
5.2. Evaluation of the general action plan with energetic analysis

In order to evaluate the general action plan, detailed energy calculations were made for the six educational building complexes. The individual measures of the action plans were applied on the buildings in the current status, so the other aspects of the obviously necessary complex modernizations could not be counted in these models.

In Table 5, illustrations explain the applied innovative building service solutions in the case of each building. The graph shows the primary energy use of service systems of the building complexes in the current and upgraded state. The energy needs of heating system are shared in proportion of the different types of heat losses. The heating energy need was decreased significantly, partially because of the thermal insulation of the building boundary structures, but mainly due to the elimination of heat loss in the air exchange, however this generates new energy needs for the artificial air handling. Renewable energies can be presented only partially in graph, because significant parts of them are already counted in the energy use of building services.

All of the overall energy performances calculated on the basis of the energy modernization proposals of action plans fulfilled the requirements for the cost-optimized and the nearly-zero-energy buildings in the cases of the six educational buildings. The amounts of renewable energy use also fulfill the 25% requirement of nearly-zero-energy buildings in all cases. Based on the above, it can be stated that using the general action plan each of the six educational complexes can be renovated not only as a cost-optimized but also as a nearly-zero-energy building as well.

Table 5. The energy indicators of the buildings in current status and after a renovation according to the action plan

School name	Hild		Bercsényi		Lukács		Baross		Dance&Art		Szabóky	
Spatial relations of buildings, axonometries, Green: ventilation Purple: PV panels Yellow: soil probes												
Status	Current	Planed	Current	Planed	Current	Planed	Current	Planed	Current	Planed	Current	Planed
Energy demand of: E_H: heating, in this: E_{surf}: cooling surf. E_{soil}: soil contact E_{w+d}: windows E_{vent}: ventilation E_{filt}: filtration E_{DHW}: hot water E_{Ah}: air handling E_C: cooling E_L: lighting E_G: energy gain Requirements: E_{pmnze}: nearly zero E_{pmco}: cost-optimal E_{pm}: general, old												
H. l. f. [q] W/m³K	0.446	0.161	0.456	0.137	0.497	0.099	0.406	0.114	0.481	0.135	0.459	0.150
E. p. [E_p] kWh/m²a	246.917	25.844	233.308	4.064	309.304	43.417	301.858	43.958	294.791	24.938	250.407	22.019
Renewable energy	5.779%	47.589%	6.355%	82.879%	3.624%	32.573%	5.107%	38.913%	5.397%	50.854%	7.374%	65.618%
Energy class	290% GG	30% AA++	274% GG	5% AA++	305% GG	34% AA++	355% HH	52% AA+	347% HH	29% AA++	295% GG	26% AA++

6. Conclusions

A common desire with our students is to make our research utilized. This can happen if our alternative modernization plans could have an impact on the design process of renovations and extensions, or before that, in the tender phase of them. As the modernization of public buildings is a public interest and because the institutions were also interested in our results, it was necessary to publish an overview research report for each building [10-15], which were disseminated after the research with my PhD thesis [19].

The energetic examinations on the complex modernizations of the secondary schools in Győr presented that the educational buildings of 1950s and 1960s could be modernized according to cost-optimized or nearly-zero-energy

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expectations in general. To be scientifically correct, it should be declare that the results of the examinations can be extended only for the buildings having the same characteristics with the analyzed ones. The six school buildings have similar energetic characteristics due to their urban situation, function, age, size, geometric, architectural, and structural features, moreover they were renovated on the almost same level, so they can be examined as a group.

Our case study based research shows similar results as other surveys on the energetic characteristics of the Hungarian building stock. The National Building Energy Strategy states that the cost-optimized modernization of educational buildings can result in 61.2% reduction, and the nearly-zero-energy aimed modernizations can result in 65.5% reduction of the overall energy performance in contrast with the existing status of the buildings [8]. Other research projects like NEGAJOULE and RePublic_ZEB also emphasize the need for the energetic modernization of public buildings with similar calculations and international examples [20, 21].

The results showed that these modernizations could not be performed with the usual methods, but they can be done with careful architectural, constructional, and building service engineering design, and with the application of effective new technologies. Important recognition of this study is that educational buildings usually have exceptionally good conditions to place soil probes under schoolyards and photovoltaic panels on roofs, and there is a mandatory need for artificial ventilation with heat recovery. This triple, mutually cooperative system is extremely efficient energetically. In this way the requirement for the 25% renewable energy use of the nearly-zero-energy buildings is also feasible.

The defined general action plan with its 12 steps can help the future modernizations of educational buildings. The wording of proposals in general action plan intentionally refers to the necessity of the consideration of the possibilities, which is an important duty and responsibility of the designers. In the field of building energetics, especially in the modernizations of existing buildings, several disciplines meet, so it is particularly important to apply the holistic approach. The interactions of simultaneously existing, often conflicting factors should be placed and ranked in the triple system of stress, requirement and performance, so the right decisions could be achieved from architectural and technical aspects as well [22]. With this kind of attitude, the complex modernizations of educational buildings can give positive examples of energy and environmental awareness for the next generations and the whole society.

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Feasibility and practicality of replacing hydroelectric dams with wind turbines

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Abstract

There is opposition to hydroelectric dams in the Pacific Northwest as they have come to be perceived as damaging to the environment. Of particular concern are the four dams on the Lower Snake River and their detrimental effects to salmon and steelhead spawning habitats. In the last couple of decades, as climate change has come front and center as a global concern, renewable generation methods have become increasingly important. Thousands of megawatts of wind energy have been installed in the Pacific Northwest. With this new influx of generation capacity there is a renewed push to remove the dams, following the logic that the dams can be replaced by wind energy. This research explores whether this is feasible and examines some of the controversies surrounding hydro vs. wind, and also the utility, environmental and economic impacts of each energy generation method.

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Keywords: Wind; Energy; Hydroelecticity; Environment; Turbines

1. Introduction

The most common forms of renewable, alternative energy used today are wind and solar. These often struggle economically to compete with conventional generation resources. Proponents of alternative energy hope to eventually replace conventional energy generating methods, such as those from combustible fuels with energy generation, in a way that has minimal adverse impacts to the environment. This research will focus solely on energy converted into electrical current for use on public power systems, in particular, the region of the Pacific Northwest. In the Northwest, there currently exists a unique scenario as alternative renewable energy in the form of wind is being sought to replace the conventional renewable energy generation of hydroelectricity.

The Pacific Northwest, with its, rainy, mountainous topography has always been ideal for hydroelectricity. The Columbia River, with its headwaters in the Canadian Rockies flows over 1,200 miles, crossing the United States Border in Washington State and emptying into the Pacific Ocean at Astoria, Oregon. The river's watershed extends across the entire Pacific Northwest, consisting of the majority of Oregon, Washington and Idaho, and stretching as far as Montana, Nevada, Utah and Wyoming (Fig.1). Because of its high flows and steep gradient, the river was surveyed by the United States Government as early as 1932 for its hydroelectric potential and currently produces over 40% of the total U.S. Hydroelectric generation [13].

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Fig. 1. Map of the Columbia River Basin, covering seven states and two Canadian Provinces. Source: Washington State Department of ecology, 2016

Even while providing low-cost, plentiful and relatively pollution-free electricity, the dams do have a downside. This toll is mostly exacted on the wildlife and fish habitats, in particular, to the salmon and steelhead populations native to the Columbia and Snake rivers. The salmon population in the Columbia River was already in decline due to overfishing, agriculture and other man-caused effects when Grand Coulee, one of the first dams, began construction in the 1930s, as a government sponsored jobs project during the Great Depression. This massive power plant, the largest in the United States by capacity, constructed nearly 600 river miles from the sea, halted salmon runs for hundreds of miles into the upper reaches of the Columbia.

Since the installation of the dams, there has been political pressure to mitigate the impacts on the salmon and wildlife, ranging from increasing expenditures on salmon recovery efforts to outright removal of the dams. However, the benefits of reliable, low-cost and relatively clean energy have thus far prevailed in public opinion over the most extreme solutions, including partial removal or removal proposals.

In the most recent decades there has been increasing competition between newer wind power and traditional hydro, due primarily to legislative requirements called Renewable Portfolio Standards (RPS) and government incentives to develop alternative energy, all of which are driven by the popular ideal of emission free, renewable energy as well as lobbying from wind power organizations such as AWEA. Over the past decade, wind farms have been rapidly increasing construction of new capacity in the Pacific Northwest, from a few hundred megawatts (MW) in the early 2000s, to over 7,200 MW presently.

Bonneville Power Administration (BPA), a self-funded Federal agency and transmission authority that serves much of the load in the Pacific Northwest, is in the position of balancing all the generation resources and the loads while trying to maintain stability of the system, address environmental concerns, and maintain low rates for the public utility customers. As wind capacity grows, so does the call from some interests to remove hydroelectric dams, especially the four Federal dams on the Lower Snake River (LSR). Therefore, this raises the, “does it make sense to replace renewable energy with renewable energy?”

2. Literature Review

Environmental issues are often economic issues, and as with all issues surrounding how resources should be allocated, tend to be controversial. The introduction of wind power to the Pacific Northwest is no different. With influence from the Federal Government to reach 20% Wind Energy by 2050 [20] and State Governments in the form of mandates, tax breaks and Renewable Portfolio Standards, as well as opinions of regional politicians, wind energy has expanded greatly in the last decade.

As more settlers headed west across the Oregon Trail, the Columbia River became more important. Steamboats began to appear on the river, and in the late 1800s Congress commissioned the U.S. Army Corps of Engineers (USACE) to build Cascade Locks to allow river navigation past the dangerous Cascade Rapids. In 1932, USACE identified for Congress 10 locations to build dams along the Columbia River in a document called the "308 Report." The dams would provide a great deal of electrical energy, converted from the mechanical energy of the steep, swift Columbia River. The dams would also enable navigation of ships far up the river, possibly as far as the Canadian Border, or beyond and provide flood control to communities downstream, such as Portland, Oregon. Since then, all the dams identified by that report have built along the entire river from the Canadian Border to the ocean, effectively taming the entire Columbia River [23].

As construction of dams continued, fisheries that Indian tribes still maintained were flooded and became unusable. Many of the dam sites had to be negotiated in order to begin construction with the sovereign Indian nations which generally allowed the construction for various reasons, usually with some consideration. At the present day, the dams have a generation capacity of over 29,000 MW, the majority owned by Federal Government agencies [13]. The regional issues of the U.S. Government's obligation to the regional tribes is nuanced and extremely complex and generally outside of the scope of this research. This research will simply acknowledge that there is significant legitimate reasoning for removal of power plants in the Columbia Basin for salmon and steelhead as well as cultural preservation.

Some local residents question the need for wind when 69 percent of the BPA controlled system is composed of hydroelectricity, a renewable resource, while others actively promote it [1]. In Washington State, Initiative 937 passed in 2006 which requires that utilities obtain 15% from renewable resources such as wind and solar, but excluded hydroelectricity, effectively considering it nonrenewable. Oregon followed suit in 2007 with legislation requiring an even more ambitious 25% renewable requirement and already expanding windfarms saw an even bigger influx of windmills following these legislations [5]. In 2016, Oregon increased its RPS to a 50% requirement from non-large hydroelectric renewable resources and outlawed coal power.

When compared to hydroelectricity, wind power is very unpredictable. While hydro can be stored behind dams for use on demand, wind is at the complete mercy of the weather. Further, just because the wind is blowing does not mean the turbines can be used. The cut-in speed, meaning the minimum wind speed before a wind generator's breaks can be released and it can begin generation is typically 6 to 7 mph and the maximum is around 50 to 60 mph. This leads to challenges with maintaining stable voltages in the system [7]. Often, wind is available when it is needed the least, which leads to having to cease hydro production and even ramp down the slow-responding "baseload" thermal plants, usually comprised of coal, gas and nuclear. Baseload plants must run at 70 to 90 percent of their capacity and cannot readily or significantly adjust or cease output without drastic losses to efficiency [14]. There have been instances when production of wind on the BPA system was so great that it was oversupplied and wind farms were ordered to cease generation, a procedure called curtailment. In some cases, BPA must compensate wind farms for curtailment which wastes generation potential and increases costs [16].

Environmental impacts of wind energy exist but are generally considered acceptable when compared to the conventional methods of generation. Neither wind nor hydro are completely carbon free. While wind turbines emit a relatively low amount of carbon throughout their lifecycle, mostly from materials production, manufacture, installation, operations and maintenance and disposal; it is unreasonable to suppose they have no effect on the environment. In fact, a number environmental scientists, while recognizing the low emissions of wind energy, urge procedure with caution when it comes to the impacts of widespread windmills [18,22]. The amount of carbon emissions, created by windmills, while not affected by the size of the windmills, is dependent on a number of factors, and not completely certain [6].

Common downsides associated with wind energy include land use, affected wildlife habitats, unsightliness and health concerns from sound and vibration [18]. Researchers for The Journal of Applied Ecology, British Ornithologists' Union, and The Ecological Society of America have found that windmills have a significant and adverse effect on birds [3,9] and bats [12]. Studies following the impacts on migration and other effects of large wind farms on larger wildlife in the Pacific Northwest are not common and may not be particularly useful given the relative newness of large scale windfarms. It is reasonable to expect that future studies will be conducted into the subject.

According to a pioneering study done by MIT researchers published in 2010, large scale wind farms raise the surface temperature of the earth and affect climate [22]. Following studies have shown that windmills can and do heat the vicinity of the windfarm by mixing warmer air with the cold air that stays close to the earth's surface, especially at night. Up to 250,000 acres of wind farms are necessary to replace the four LSR dams. The above environmental impacts by wind turbines are not unique to the Pacific Northwest, generally speaking, although the specific effects they may have on the Northwest ecosystem are a topic of research unto itself. One environmental impact of wind power that is unique to the BPA system are the adverse effects of not using hydroelectric storage on the Columbia River Watershed for generation. If water is not used for generation it must be spilled, which causes greater amounts of dissolved nitrogen gas to fill the river. This is harmful to fish populations [2,4]. Debatably, wind is not to blame for this problem at all, the dams, and of particular interest to this research, the LSR power plants, are. However, wind power has halted some workaround practices, such as generation through certain hydro power plants that have been in place to deal with the oversupply situation which now causes a need for curtailment.

Arguably, this may be the best reason to remove the LSR dams. In fact, there has been a push for several decades to remove dams in the Pacific Northwest, especially the four dams on the lower Snake River, in hopes of restoring the habitats of salmon. Due to political pressure, the U.S. Army Corps of Engineers was ordered to investigate the feasibility of removing the dams in 1995. After a seven-year effort of economists, scientists and engineers, the study was released in 2002. Removing the dams will create its own environmental impacts. The study predicts overall improvements to fish survival in the long term by removing the dams, but also notes there are uncertainties and risks associated with dam removal, with degradation of the river system in the short term [19]. The majority of wind capacity, RPS, Federal and State goals in regards to wind power were realized after this study, so participants in the study could not foresee and did not implement those outcomes into the findings.

3. Methodology

Qualitative research methods were used to assess the politics behind the arrival of wind power to the Pacific Northwest and whether the public actually wants wind power to replace hydroelectricity. Hydroelectricity and wind power in the Northwest is a very complex issue and there are numerous aspects to public opinion. News articles and opinions are taken from newspapers generally considered reputable such as The Oregonian, a Portland, Oregon based newspaper which covers many of the issues facing the region's electricity as well as BPA, The New York Times and Forbes. Tying it all together, editorials from energy technologists and environmentalists were analyzed to discuss the merits (as well as demerits) of wind power in a region where there is primarily another source of renewable energy.

In general, the question being asked relative to public opinion of dam removal or wind energy is, "Which, if either, does the public really want?" whether that desire is more renewable energy, more economical energy, less impact on the Lower Snake River System, or something else altogether. The few comprehensive polls that are available and considered trustworthy were analyzed. Opinion pieces were examined, and where possible the background of the opinion piece authors was researched. By necessity, some subjective judgments may be made on the motivation behind certain political issues based on the best available evidence.

Quantitative analysis was completed using the information on generation that BPA makes available to the public to determine what sources have been utilized historically. Historical generation data retrieved from BPA's website, was compiled and organized. The data consists of the total load on BPA's system, and the number of megawatts generated by thermal, hydro and wind from 2007 to present. Most power plants describe themselves by their capacity. That is, the maximum amount of power they can produce under ideal conditions. Capacity factor is the amount power plants actually produce divided by their capacity. A challenge arises with new wind capacity being added yearly and, in some cases, monthly, the data doesn't show the time and date that each windmill went online to the BPA system, making the actual wind capacity of the system difficult to determine.

Intermittency were observed by comparing times of above average loads to times when below average wind is being generated. Conversely, times of high wind generation will be compared against times of low demand. Further, times when all wind on the system are generating less than 100 MW, which is the approximate output of one, small, hydro unit at an LSR power plant were measured and charted for clarity.

In order to compare which electricity generation method is cheaper, new wind, or hydroelectricity from existing power plants, it is useful to use the Levelized Cost of Electricity (LCOE). Doing so requires a number of assumptions. The U.S. Energy Information Administration provides data for building new hydro capacity. The LSR power plants have been in operation since 1962, 1969, 1970 and 1975. Economic life of the investment is variable for both energy generation sources. For wind, a life of 20 years will be assumed [11]. For hydro, assuming an economic lifespan becomes a bit more complicated since a dam is constructed of many components with vastly different lifespans. 40 to 80 years are safe assumptions for the many of components although the structures can last in excess of 100 years [10]. Determining a weighted average that is useful and reflective of capital costs and lifespans is beyond the scope of this research.

4. Data Analysis

Objective polls on the subject of whether or not the general public supports dam removal are somewhat difficult to find. The public tends to be generally positive toward the idea of renewable wind power, but negative toward the idea of removing dams. Thus, there exists a challenge in this disconnect, and discovering if the public would truly rather be supplied electricity by wind farms rather than dams. A poll by Earthfix and DHM Research done in 2011 with a sample size of 1,200 people divided evenly between Idaho, Oregon and Washington found that support of water quality is the highest priority. The Earthfix study also gives insight into how people viewed wind power. On average, study participants estimated that 8.4 percent of electricity comes from wind, but believe that wind energy should provide 18.6%. In reality, according to the data from BPA, 7.3 percent was provided by wind in 2011. The regional public also believed that hydroelectricity should be reduced from their perceived percentage of 41.4% (reality 67.4% in 2011) to a target of 29.8% [8]. Thus the public generally misunderstands where electricity comes from, apparently unaware of how much is produced by hydro in the region. A chart demonstrating the production trends over this period of time is shown in Fig. 2. The overall average production of wind, hydro and thermal between 2007 and 2016 is 7.5, 67.7 and 24.8 percent respectively.

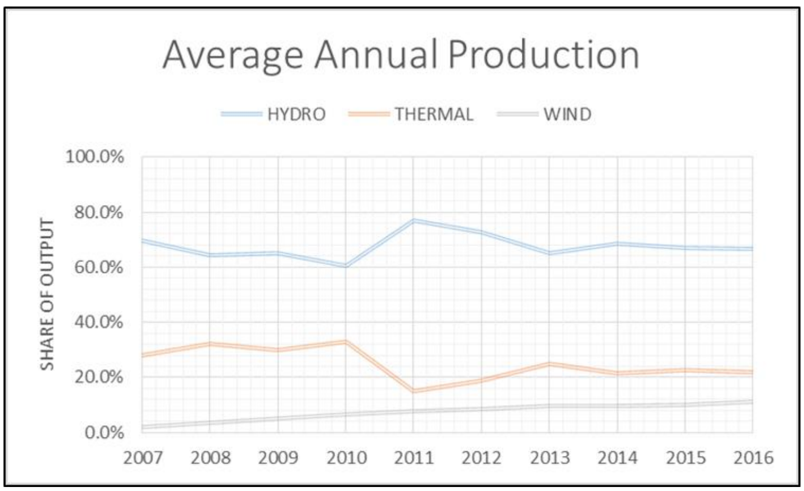

Figure 2: Average output shares of generation output since 2007 Source: US Energy Information Administration, 2016a

However, even though the public underestimates how much of their electricity it gets from hydroelectricity, and in spite of its views that hydro should be reduced even further, it does not appear to translate to a desire to remove the Lower Snake River power plants to replace them with hydro. According to the same study, 31% of the public views removal of the Snake River dams as "extreme" and while 34% think it is a necessity to "consider whether the dams on the Lower Snake River can be removed to save salmon species in the Northwest without hurting the economy or significantly increasing electric rates." Only 8% believed in removing the dams immediately "to save salmon species in the Northwest" [17].

Other polls sponsored by Northwest River Partners, a hydropower advocacy group claim that as high as 71% of respondents view dam removal as extreme, 67% would not be willing to reduce the amount of hydropower, 69% believe hydropower does not contribute to climate change and 88% view hydropower as a renewable resource similar to wind and solar [15]. However, the complete polling questions and methodology was not readily available for review.

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Over 60 percent of the time when there is high load demand, wind power is producing at below average rates. In other words, it's not available when it's needed most. Conversely, when demands are low, such as at night, wind commonly picks up, producing electricity that is unneeded. This is a problem that can result in curtailment. In 2011, high springtime flows required significantly higher than usual springtime generation. When in 2011 and 2012 high flows came simultaneously with high winds grid managers had more than they could handle. Consequently, BPA ordered wind producers to cease production, which deprived them of generation revenues.

Approximately 53% of the time, wind energy is producing less than 2% of its capacity on the BPA system, under 100 MW, or one generator at one of the LSR power plants (Fig. 3). For this research, this is considered negligible. Hydroelectricity, on the other hand, does not have the same problems (Fig. 4).

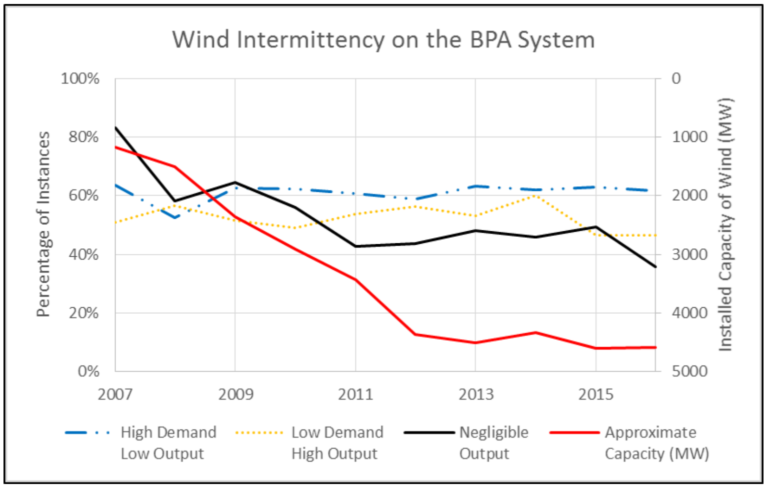

Fig. 3: Wind generation intermittency on the BPA system (2007-2016) Source: US Energy Information Administration, 2016a

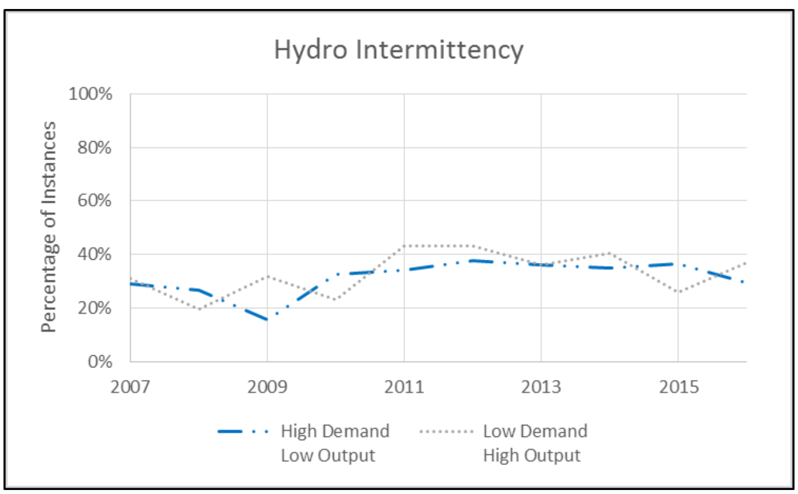

Fig. 4: Hydro generation intermittency on the BPA system (2007-2016) Source: US Energy Information Administration, 2016a

While the generation can vary with the flows of the river, it is relatively stable. Hydro generation is at its lowest in summer, as most of the snowpack is melted and the river flow drops. The reduction in energy generation will then need to be made up by another generation resource, usually thermal. While drought years can cause production to be cut even further, this is somewhat unusual in this region. The percentage of instances when high demand received low output from hydro are below half. Conversely, the number of times when hydro output exceeds the average when demand is low is zero. This indicates control over hydroelectricity, and an ability to utilize it, for the most part, when needed. There are no instances of negligible hydro generation on the BPA system.

5. Conclusion

Wind power should be appropriately recognized for its merits, which include reduced reliance on fossil fuel consumption. However, wind should not be utilized to replace other forms of renewable power, especially hydroelectric as it is not nearly as reliable and does not provide the additional benefits that hydro dams provide. Public opinion does not warrant removal of the dams at this time as indicated by the limited public opinion materials available at this time. RPS should include hydro, take into account the high costs associated with their implementations, and be practical toward the goal of reducing carbon emissions, pollution, and fuel consumption rather than trying to select preferred renewable technologies.

While there are ways to address the challenges of intermittency of wind, they are not inexpensive. Currently the most practical way of dealing with these challenges on the BPA system is to continue to utilize the LSR power plants to balance transmission. In the future, pumped storage and compressed air technologies may become necessary to utilize as well. There are benefits to the environment of the Pacific Northwest to remove the LSR dams, in the form of fish and wildlife improvements which may improve the overall ecology of the region. However, replacement with wind resources may offset some of the benefit to the environment due to large amounts of land use, and possible climate alteration. The fossil fuel burning plants required to compensate for the loss of the LSR power plant capacity will result in greater greenhouse emissions than exist currently.

It is not currently cost effective, nor is it ever likely to become so to replace existing hydro capacity with new wind. Storage solutions will reduce the intermittency disadvantage of wind, and can likely reduce some long-term costs as well, but will still have capital and O&M costs associated. Therefore, due primarily to high costs loss of stability to the BPA system, the replacement of renewable hydro generation by fossil fuels, with unclear benefits to show for it, this research concludes that the Lower Snake River power plants should not be replaced by wind generation.

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Heritage Building Information Modelling (HBIM) to make informed decisions when retrofitting. A case study

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Abstract

No-fines concrete (NFC) dwellings is a very common type of housing in the British urban landscape and other parts of the world. However, the fabric of these buildings can not be considered efficient anymore. Therefore, city councils and individuals aim to improve their energy efficiency. Unfortunately, accurate information about the thermal efficiency of this type of buildings is not available, as it happens with many other types of existing buildings. This work forms part of a British Council-funded Institutional Links project to create a Heritage Building Information Modeling (HBIM) web-portal to share key information about heritage building typologies. This paper presents the case study of NFC buildings.

For this purpose, three NFC dwellings (C1, C2, and C3) were monitored, gathering in-situ key information about the thermal performance of the fabric to create a HBIM model where to display the information. It was found that the original U_{NFC} = 0.85 (±0.052) W/m^{2}K, could be reduced to 0.22 (±0.013) W/m^{2}K if 110mm of external wall insulation (EWI) was added. It was also found that the initial in-situ U-value (0.85 W/m^{2}K) was 50% lower than those assumed (1.71 W/m^{2}K). Based on these outputs, two Building Energy Models (BEM) were created and compared, using SAP. One included the traditional assumptions and the other model the actual in-situ data. Higher starting U-values resulted in predicting an unrealistic 27% heating consumption reduction in comparison to the actual 15.5% reduction if the in-situ measured thermal baseline was used.

In conclusion, the use of assumptions for the fabric of a building lead to inaccurate predictions, a performance gap will appear and expectations will be jeopardised. Only the use of actual data can help make optimal decisions. Therefore, the HBIM models will help future stakeholders to make informed decisions based on actual data when trying to improve the thermal performance of NFC buildings.

Keywords: Building Performance Evaluation; No-fines concrete; Retrofitting; External wall insulation; Heating energy consumption

1. Introduction

No-fines concrete (NFC) was a construction method for mass-production of low-rise dwellings at a low cost. Around 300,000 NFC houses were built in the UK between 1940s and 1980s [1]. Although this research is based in the UK, NFC was extensively used for housing in South Africa [2], the Middle East, West Africa and countries like Venezuela or Hungary [3]. Therefore, some of the findings will also have a global impact.

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The fabric of the NFC buildings can not be considered efficient anymore [4]. Uninsulated solid walls, like those made from NFC, contribute a large proportion of UK CO_2 emissions due to their poor thermal performance and jeopardise the level of comfort of their occupants [5]. The Council of a city in the South West of the UK carried out an ambitious large scale retrofit programme to improve the thermal performance and comfort adding external insulation to hundreds of its social houses. The target of the council was to reduce the CO_2 emissions of the city by 40% and energy use by 30% by 2020 against a 2005 baseline, and to improve the thermal performance of the exterior wall to match the requirements of current Building Regulations for new residential buildings. Therefore, the proposed over-cladding project aimed to reduce the heat loss through the walls below 0.25 kW/m^2 [6].

In order to decide what measures are optimal for the thermal improvement of existing buildings, it is necessary to know the actual heat loss of the original fabric, called thermal performance baseline [7]. However, there is a lack of information about the materials and thermal behavior of the fabric of existing buildings [8]. This is especially limited in the case of NFC homes. The aim of this study was to gather information about the original fabric of NFC buildings and quantify the heat loss reduction after adding EWI, to find if the targets were actually achieved.

This work forms part of a British Council-funded Institutional Links project to create a Heritage Building Information Modelling (HBIM) web-portal to share key information about NFC buildings, as a starting point to later cover other building typologies. Therefore, the information collected will be input within a HBIM model for rapid and user-friendly consultation and visualization. The HBIM model is expected to be of benefit to any stakeholder involved in implementing thermal improvements to NFC dwellings, especially homeowners, designers, consultants, and councils, since there is currently little accurate information.

This paper commences by reviewing available literature on the thermal performance of the fabric of NFC buildings. This is followed by the research methodology, findings, discussion and conclusions drawn from the research.

2. Literature Review

The aim of the literature review was to identify and describe relevant research conducted over the last few decades on the thermal performance of no-fines solid walls. Literature searches have been carried out in following databases for the period 1965-2017: Elsevier Science Direct, Research Gate; Construction Information Service; Iconda; Emerald; DOAJ, SpringerLink, JSTOR.

The research available consistently shows that the predicted savings of adding insulation to solid walls are typically, significantly greater than the actual energy savings achieved [8, 9, 10, 11]. One of the primary reasons is the inaccurate assumptions regarding the baseline performance of the building envelope and most importantly of the solid wall [8].

The thermal performance of a fabric is based on three key sets of information, its area and linear thermal transmittance and its air-tightness [12]. The thermal performance baseline based on standard values may differ to the baseline performance of the actual building under study, especially when default U-values are used [13]. They are a significant source of uncertainty [14, 15]. In situ measurements of the U-values and air permeability close this existing “performance gap” between measured and modelled data [16].

NFC is a mix of clean aggregate and Portland cement with no fine aggregates (sand or gravel) [17]. The result is an open textured cellular concrete that can have different levels of porosity depending on the level of compaction. The thermal properties and thickness of the layers of existing NFC walls are in general unknown. The literature reveals a standard wall, based on a NFC core of different thicknesses depending on the number of stories, usually finished externally with a layer of 15mm cement-sand pebbledash and a variety of interior finishes [17].

RdSAP is a simplification of the Standard Assessment Procedure (SAP), which is the regulatory tool used in the UK to assess the energy performance of new dwellings for compliance with Building Regulations. RdSAP is the building performance certification tool used in the UK for estimating the building performance of existing dwellings [8]. RdSAP allocates a generic safe estimate U-value and thickness for any NFC wall. For the buildings under study in this research, it assumes a thickness of 250mm and the same U_{NFC} of 1.71 W/m^{2}K for any pre-cast concrete panel, steel framed, poured concrete or NFC wall built between 1967 and 1975 [18].

The process of transferring a real building to a computer model introduces uncertainties due to the simplifications made [19]. The assumptions made to fill the parameters to create a model not always match the actual building. For instance, the literature revealed that the U-value of the NFC wall can vary in a range from 0.94 W/m^2K [20] for the in-situ values to 1.71 W/m^2K [17] for the assumption used in RdSAP. This is due mainly to the differences of mixture, density and compaction (air voids) of the different types of concrete core specimens studied. In other words, the use of assumptions regarding U_{NFC} could imply an uncertainty of up to 45% between in-situ U-values and assumed ones. Therefore, the thermal transmittance (U-values) of exterior walls represents a source of uncertainty when estimating the energy performance of dwellings [15].

This review demonstrated that the accurate determination of the thermal performance of NFC dwellings is not an easy task because of the number of factors adding uncertainty. The information to create accurate models is insufficient and is contained in separate documents. Because of this, generally, BEM models tend to be based on standard “average” assumptions and are created using tools such as RdSAP that over-simplify the model. A further investigation in-situ of the thermal transmittance of this type of walls and permeability of the fabric is required to provide paramount information for future retrofit projects [8, 21, 22,23].

3. Methodology

This research is reliant on a combination of quantitative data collection techniques for in-depth exploration from multiple perspectives. The quantitative research methods aim to collect numerical data to define the fabric of the NFC buildings studied (1). This data is used to create Building Energy Models (BEM) to explain and try to predict their pre and post-EWI thermal performance (2). Finally, these predictions based on assumptions are compared with predictions based on actual in-situ data collected to determine the existence of possible performance gaps (3).

A sample of three no-fines concrete (NFC) dwellings, two mid-terrace (CASE 1 and 2) and one end-terrace with an extra external wall (CASE 3), built in 1971 and with similar floor area and construction but different occupants were monitored.

Fig. 1. Three No-fines concrete dwellings. C1, C2 (mid-terrace), and C3 (end-terrace).

1. Several procedures were carried out according to corresponding standards and good practices to gather the following information before and after the insulation was installed:

- Dimensions, heating, hot water, lighting and ventilation systems and controls, by carrying out a visual survey.
- Thermal transmittance of the NFC walls by carrying out an in-situ heat-flux test in one of the properties (C2).
- Air leakage by carrying out an air permeability test in each property.

2. This data was used to create a Building Energy Model (BEM) using SAP, to determine the thermal baseline of the fabric of the NFC dwellings, and the impact of EWI on the heat loss of the fabric of this type of dwellings.

3. RdSAP is a regulatory tool designed to assess the building performance using default U-values and airtightness, the same standard occupancy, heating habits and weather location to enable fair comparisons between energy ratings of properties throughout the UK for compliance purposes [24]. This high level of simplification of the current model made Kelly et al. [25] to conclude that RdSAP is "grossly inaccurate". However, RdSAP is extensively used due to the lack of information on materials and thermal behaviour of the fabric of existing buildings. SAP also has limitations to include the actual occupancy, ventilation, heating patterns and weather data, but it allows to include the in-situ data of the fabric to determine the heat loss of the building [26] (Sierra et al. 2018). Therefore, the BEM models were created using SAP for comparison between assumed and actual in-situ heat loss values of the fabric.

4. Results and Analysis

The initial part of this section presents the thermal performance baseline of the fabric of the NFC dwellings, which was determined based on the data collected from the in-situ heat-flux test, airtightness test, and building survey before and after adding EWI. The second presents the results of the two BEM models and compares them.

A visual survey was carried out to produce dimensioned floorplans and to produce the specification of fabric and services. It was found that the dwellings were built featuring solid NFC walls, solid concrete slab ground floors and pitched trussed rafter roofs insulated with 100mm of rock-wool at ceiling level. Figure 2 shows a specimen taken from the wall of C2, which revealed that the solid NFC walls were formed by 15mm of pebbledash external render, and a core of 280mm of NFC, internally finished with a 15mm air layer followed by a 40mm paramount panel. 110mm EPS insulation boards (λ = 0.032 W/mK) were attached lately to the external walls and covered with 15mm of render.

Fig. 2. Sample of the NFC wall formed by 280mm NFC and 15mm thick external render

The accurate prediction of the reduction of the heat loss of a dwelling relies on a good estimate of the baseline of the thermal performance of the NFC fabric and most importantly of the U-value of the external walls to be insulated. The necessary key data was obtained carrying out an in-situ heat flux measurement to determine the amount of heat loss through a north-facing NFC wall of one of the case studies. The test was conducted over a two-week period before (November 2016) and after (March 2017) the insulation was added. This period is considered long enough to take into account the thermal inertia of the NFC wall and temperature stability on heat flux, allowing the result to converge [16, BSI, 2014).

It was found that the thermal transmittance measured in situ of the original NFC walls was U_{NFC} = 0.85 (±0.052) W/m^{2}K, some 50% better than the standard value used in RdSAP (1.70 W/m^{2}K). The post-EWI transmittance measured in situ was found to be U_{NFC} = 0.22 (±0.013) W/m^{2}K. Therefore, the target of the Council to reduce the heat loss through the walls below 0.25 W/m^{2}K was achieved. RdSAP, on the contrary, assumes in its calculations to determine the heat loss of the fabric a post-EWI thermal transmittance of 0.35 W/m^{2}K.

Higher starting U-values result in predicting unrealistic higher energy savings. A calculation using SAP reveals that if the same 110mm (λ = 0.032 W/mK) of EWI are added to a wall of U = 1.70 W/m^{2}K ($U_{insulated}$ = 0.245 W/m^{2}K), this produces a reduction of the heating from 111.55 to 81.43 kWh/m^{2}yr, a 27% reduction. If the same insulation is added to the actual wall of U_{NFC} = 0.85 (±0.052) W/m^{2}K ($U_{insulated}$ = 0.22 (±0.013) W/m^{2}K), the heating drop is smaller, from 95.2 to 80.1 kWh/m^{2}yr, only a 15.5%. An inaccurate reduction of 27% of the heating consumption in comparison to a

15.5% reduction if the actual baseline is used. Therefore, the second target of the Council to reduce the energy use by 30% was not achieved, although RdSAP was predicts that it will come very close to it.

In addition, two air permeability tests were carried out, before and after the insulation was installed. The tests were conducted in accordance with BS EN 13829 [27] following the procedures set out in the Air Tightness Testing and Measurement Association [28]. It was determined that the fabric of these NFC dwellings had a high level of permeability, between 14.36 and 18.33 m^3/hm^2, depending on the case study, which was minimally reduced when the outer insulation was applied (13.92 to 17.56 m^3/hm^2). Far away from the air permeability limit of 10 m^3/hm^2 required by the current British Building Regulations.

Table 1 gathers the assumptions generally used when assessing existing buildings and the outputs of the visual survey and in-situ tests carried out. The data will be used to create two SAP models to compare the thermal performance of the NFC case study before and after retrofitting, depending on the data included.

Table 1. Building specification data used to create the SAP models using Case study 2.

Parameter	CASE Study 2 in-situ	CASE Study 2 assumptions
External wall area	55.56 m^2	55.56 m^2
Total floor area (m^2)	94.3m^2	94.3m^2
350mm External walls	U_{NFC} = 0.85 W/m^2K	U_{NFC} = 1.71 W/m^2K
490mm (100mm EWI)	$U_{NFCwall}$= 0.22W/m^2K	$U_{NFCwall}$= 0.35 W/m^2K
Roof: 100mm insul. at joists	U_{roof} = 0.40 W/m^2K	U_{roof} = 0.40 W/m^2K
Ground floor (100mm slab)	U_{floor} = 0.51 W/m^2K	U_{floor} = 0.51 W/m^2K
Window areas (m^2)	12.65 m^2	19 m^2 estimated by age & floor area
Double glazed windows	U = 2.0 W/m^2K	U = 2.60 W/m^2K
Infiltration uninsulated	18.33 m^3/hm^2	Unknown - Estimated based on age
Infiltration insulated	17.56 m^3/hm^2	Unknown - Estimated based on age

The heat transfer coefficient (HTC) defines the thermal baseline of the fabric of NFC before and after EWI is added to the walls. It includes the heat loss through the external walls and other elements such as ground floor, roof windows etc., the heat loss due to thermal bridges and the heat loss due to infiltration. HTC defines the thermal quality of the fabric and is a key figure for predicting the amount of heating demand to achieve comfort within a dwelling. Figure 3 compares the wall heat loss (W/k), before and after the EWI is applied. The heat loss through external walls represents a 23% of the total heat loss of the entire fabric of C2, which was reduced a 15% after adding EWI. However, when assumptions are used for the fabric, the reduction in total heat loss due to EWI is predicted to be reduced by 27% for C2, since the heat loss from the walls was assumed to be 33% of the total heat loss of the fabric. Therefore, the impact of adding EWI on the total heat loss of the fabric was smaller than expected due to the use of inaccurate data.

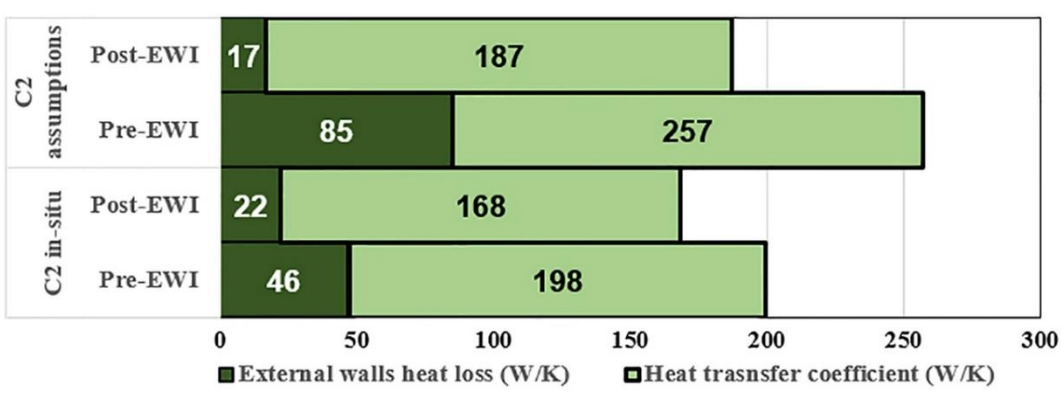

Fig. 3. Comparison between HTC based on assumptions and in-situ data

5. Conclusions and recommendations for future research

The aim of this study was to gather information about the fabric of NFC buildings and quantify the fabric heat loss reduction after adding EWI to cover the literature gap offering reliable information.

The thermal transmittance of the studied NFC wall was found to be U_{NFC} = 0.85 (±0.052) W/m^{2}K, some 50% better than the standard value used in RdSAP (1.70 W/m^{2}K) to determine targets. When the EWI was added the transmittance was reduced to U_{NFC} = 0.22 (±0.013) W/m^{2}K. Therefore, the target of the Council to reduce the heat loss through the walls below 0.25 W/m^{2}K, was achieved. It was also determined that the fabric of the studied NFC dwellings had a high level of permeability, between 14.36 and 18.33 m^3/hm^2, which was minimally reduced when the outer insulation was applied (13.92 to 17.56 m^3/hm^2). Therefore, after being retrofitted, the dwellings comply with the requirements of current British Building Regulations for walls to keeping the heat loss through them below 0.25 kW/m^2, but not with the air permeability limit of 10 m^3/hm^2.

A comparison between assumed and actual in-situ heat loss values of the fabric (HTC), demonstrated that the impact of adding EWI on the total heat loss of the fabric was smaller than expected due to the use of inaccurate data. Higher starting U-values resulted in predicting an unrealistic 27% reduction of the fabric heat loss in comparison to the actual 15% reduction if the in-situ measured thermal baseline was used. HTC is a key figure for predicting the amount of heating demand and energy saving targets. An inaccurate reduction of 27% of the heating consumption is predicted in comparison to a 15.5% reduction if the actual baseline is used.

The accurate prediction of the reduction of the heat loss of a dwelling relies on a good estimate of the baseline of the thermal performance of its fabric and most importantly of the U-value of the external walls to be insulated. The use of assumptions for the fabric of a building lead to inaccurate predictions, a performance gap will appear and expectations will be jeopardised. Only the use of actual data can help make optimal decisions. Therefore, the in-situ data gathered in this paper will help future stakeholders to make informed decisions based on actual data when trying to improve the thermal performance of NFC buildings.

A Heritage Building Information Modelling (HBIM) web-portal was created to share this key information about NFC buildings, as a starting point to later cover other building typologies. The HBIM portal will act as a template for similar case studies, for rapid and user-friendly consultation and visualization of the results of each study. A BIM model was created in Revit Autodesk, based on the data gathered during the visual survey. Then, structured object attributes were added allowing queries about the specifications, and key in-situ thermal performance data such as U-values and permeability of the NFC dwellings, in order to reduce fragmentation and lack of the information.

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Investigating the hindrances of implementation of Occupational Health and Safety among Small Medium Enterprise's in the Gauteng Province of South Africa.

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Abstract

A positive safety culture requires participation of all stakeholders in construction industry, and is shown through the safety-related knowledge, attitudes, beliefs, behaviour and practices of each worker. Therefore, the study is investigating the hindrances in the implementation of occupational health and safety (OHS) among small medium enterprises (SME'S) in the construction industry in the Gauteng Province of South Africa. A structured questionnaire was distributed to different construction companies and construction workers. From the 70 questionnaires distributed, 42 were brought back and they were all valid and usable. Findings from the survey results obtained from the chosen respondents revealed health safety was known and practiced, however, there are hindrances in the implementation such as poor regular inspections and audits, poor management, poor supervision, lack of material and components, lack of management commitment, equipment and tools, poor communication between workers, poor employers involvement, lack of training and risk education to name a few were the major hindrance in the implementation of occupational health and safety among SME's. Furthermore, if the challenges could be addressed appropriate and effectively result could manifest such as increased productivity; improve quality work; contractors growth and reduced claims; reduced accidents; reduced rework; improved schedule performance. Management and leadership at all levels are therefore encourage to improve construction OH&S in South Africa among SME's. Moreover, occupational health and safety of the workers is not negotiable, is all pervasive, increases productivity, and leads to better performance, improve the company image, reduced claims and accidents also reduce lost times spent on injuries. The concept of OHS implementation must be emphasized by the client and the consulting team by way of having occasional not once off, a major workshop to be held three times in a year, to increase the awareness and the seriousness of the implementation of OHS.

Keywords: occupational health and safety, small and medium enterprises, south africa.

1. Introduction

According to [1], the construction industry creates employment and serves as a means of generating income for many people and also as a means of application of technologies in various degrees. Therefore, the sector engages about 240000 workers in South Africa thus contributing significantly to the gross domestic product (GDP) [2]. Nonetheless, the construction industry can be interlinked with the economy of a country and this often is an indicator of how healthy the state of the said economy is. Therefore, if the construction sector and the economy of a country are linked, it is necessary for the sector to effectively attend to the welfare of the workers in that industry [3]. Moreover the sector is associated with high risks particularly for workers nonetheless its importance in the social and economic development in South Africa [4; 5]. [6] Reported that the construction industry has great number of injury and fatality among workers

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and this is substantiated by the [7] that many construction workers become unfit at one point or the other as a result of minor injuries or some kind of problems in their health.

Health and Safety (H&S) is the responsibility of everyone at work, construction companies have to be aware that they are responsible for managing and improving issues related to H&S on construction sites [8]. This is because construction, to a large extent, is a labour intensive industry and depends on the availability and safety of workers to complete current and future projects [9]. Despite refined H &S regulations in most countries, high rates of accidents and fatality persist. The regulations and procedures intended to prevent such accidents are usually mandated by the appropriate occupational safety authority in each country [10]. The academics and professionals within the construction industry believe that regulations and legislation on their own cannot achieve the desired goal of zero accidents and incidents on construction sites, but the latter can be achieved with the involvement of the stakeholders in the industry [11]. Adherence to regulations and legislation is not the only way to ensure safety on the working environment however it provides a basis for the employment and enforcement of good construction practices at minimal cost [11]. Issues such as injuries, fatalities, and delays, financial losses can result as result of poor regulations and standards in a construction work environment [9;10].

[12] Promotes the establishment of a workplace that minimizes active risks and hazards, and emphasis the implementation of mitigating factors to either reduce or eliminate these risks and hazards. [13] Identified that productivity and quality, which are vital elements of the value chain on a construction site, are negatively affected by poor health and safety implementation. Construction workplaces are potentially seen to be the most risky and a place where accident are common. Therefore, workers are at the risk of injury and in extreme cases death, if their exposure to construction sites is not controlled [14]. According to [9], construction is described as a "dangerous, risky and hazardous task, to emphasize the above statement the United Kingdom;[15], agreed that in the last twenty-five years alone over 2800 construction workers have died due to construction accidents, with even more workers having suffered from serious injuries. "This is an unacceptably high figure and the industry needs to devise proper solutions to these problems" [15]. For many years, construction has consistently been among those industries with the highest injury and fatality rates [9]. In theory, most construction injuries sustained on site can be prevented or controlled. Unfortunately, this goal became unachievable and compliance among the stakeholders has been very inactive [16]. Prevention and control of risk in construction industry is a consistence global challenge, construction have been considered having the worst safety records among its diverse economic sectors of its kind. In addition to the loss of life and reduction in the quality of life of construction workers, construction incidents lead to project delays, increase project cost, medical burden, and other negative consequences [17].

2. Occupational health and safety in South Africa

Worldwide construction industry contributes a large number of injuries [18;10]. However, construction in developing countries, including South Africa, performs worse than construction in developed countries [18]. Furthermore, there is a high level of non-compliance with H&S regulations in South Africa. Previous research findings indicated that, at the organisational and site level, this poor performance in construction H&S is attributable to a lack of management commitment, inadequate supervision, and inadequate or lack of H&S training [18]. Moreover, a lack of worker involvement, personal risk appreciation and work pressures also contribute to poor implementation of health and safety. Management and leadership at all levels are therefore important to improve construction H&S in South Africa. Leadership needs to manifest itself among all the stakeholders, commencing with clients and including project managers, designers, quantity surveyors, contractors, manufacturers and suppliers [19].

The cost of an accident (CoA) contributes substantially to the cost of construction, which in turn creates a financial motivator for all stakeholders (including clients) to address H&S. However, a pre-occupation with cost, quality and time by stakeholders marginalises the potential realisation of the benefits of optimum H&S in the form of enhanced overall performance [20;21 &23]. The high level of non-compliance in building construction indicates that there is a lack of understanding and appreciation for the synergistic role of H&S and ultimately, a business case for H&S. Internationally and in South Africa, poor H&S implementation is often attributed to a lack of respect for workers in the building construction industry in which the workforce is treated as a low-value transient resource with little investment in their development and insufficient attention to their welfare [21; 23]. An understanding of construction H &S is handicapped by lack of available statistics, and in particular that from the Compensation Commissioner. The 1999 statistics [18; 20 &21] indicated that the construction industry accounts for around the third highest number of fatalities per 100 000 workers, and the ninth highest number of permanent disabilities per 100 000 workers. The fatality rate in the construction industry is approximately20 per 100 000 workers, or approximately150 fatalities per year excluding construction-related motor vehicle accidents, Motor vehicle accidents account for approximately another 100 fatalities per year [21 &23].

The high rate of non-compliance with the requirements of the Construction Regulations, which amounted to 50% of construction sites, indicates that H&S in the construction industry in South Africa lags significantly behind compared to other developed countries. The construction industry currently has the third highest prevalence of HIV positive workers [21] and the industry faces an increasing loss in workdays due to absenteeism and reduction in productivity, skills shortages and increased costs of construction due to rising overheads. The CoA is estimated to be around 5% of the value of construction costs which is ultimately passed onto clients. Moreover, inadequate H&S or a lack thereof negatively affects other project parameters such as productivity [19]. The global poor H&S performance recorded in the construction industry has resulted in H&S regulations being subjected to major revisions during the last three decades [18].

The primary objective of any H&S legislation is the prevention of accidents and their consequences in terms of injury, disablement and fatality, and ill health within the work environment. The achievement of this objective depends on good legislation supported by effective, sensible and accountable enforcement [21; 24 &25]. The introduction of H&S legislation in member states of the European Community was accompanied by enforcement of the legislation, which highlighted high levels of noncompliance with more than half of the sites being shut down in Portugal [26; &27]. After 1994 the government of South Africa was confronted with the dual challenge of reintegrating the country into the global economy as well as positioning itself to deal with the challenges of the new democratic order [21;22; 28 &29] . With the objectives of economic growth in mind, the government started promoting the development of SMMEs. The main objectives were to generate employment, redistribute income and become globally competitive [30].

3. Small and Medium Enterprises (SME's) contractors in South Africa

The growing importance of SMEs is clear, and SMEs currently account for about half of all people in formal employment in South Africa. This is a remarkable achievement, given the restrictions entrepreneurs face in this country, namely the real regulatory. As indicated in the report of the 2004 SME survey led by [22 & 23], SMEs in South Africa are alive, well and regard themselves as highly competitive. However, few SME owners give the government credit for their initiatives and efforts to promote SMEs. [22] States that given the amount of resources being ploughed into SME development, the situation reflects poor communication rather than poor strategy. The survey also shows that less than half of the SME owners were positive about legislation, the impact of skills development programmes and the impact of BEE, the latter having more negative than positive scores. A low 12% positive rating was given for the impact of general government incentives for SMEs [28; 29& 30]. Because of the many neutral responses (a quarter to a third) on most issues, government has an opportunity to use communications to change perceptions [22;28;29&30].

The lack of sufficient capital and credit is often a major handicap in the development of SMEs, especially in their growth stages. In developing countries worldwide, close to 95% of all SMEs have to rely solely on the personal resources and initiatives of the owners [22 &24]. The existence of a cheap source of labour, combined with the low socio-economic status of workers are major obstacles to improving OH&S as this limits workers' capacity to resist working under poor OH&S conditions on sites [29 &30]. Low skill levels linked with the adoption of labour intensive methods by the construction industry in South Africa and many other developing countries means managing OH&S can be challenging. It is clear that changing the attitudes of SMEs in construction must be handled to ensure workers' rights are not flagrantly abused in an industry setting where large numbers of the labour force are unskilled and largely uneducated [22;24 &30].

SMEs do not create better quality jobs than large enterprises [31]. SMEs are usually created as a last resort and not as a first choice of employment and therefore have limited growth potential [22]. Evidence is also inconclusive about SMEs being more innovative than large firms. It is said that large companies may exploit economies of scale and more easily undertake the fixed cost associated with research and development [31]. All in all, many authors such as [22;26;27 &31] reported on the importance of SMEs and that small business was seen as the essential condition for economic growth. In contrast, different role players are offering assistance in many areas, there are still many failures. This indicates that the type of assistance is inadequate, irrelevant or not given when needed. [1], in their research using

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Kenya as a case study, found that the safety of construction workers within the SME 's organisation was not given urgent attention on most construction sites. Workers on a construction site are at risk of being injured by construction equipment, while carrying out their tasks, or they could be injured if safety procedures are not adhered to. There is no guarantee that construction workers will not be injured on a project [23]. The best that can be achieved is to minimise possible injuries or deaths by posting safety procedures around the construction site so as to assist in the implementation of occupational health and safety [32 &22].

4. Hindrances of implementing OHS among SME's

Presently, SME owners in South Africa have numerous challenges to overcome. [22; 23; 28; 30&31]compiled the following list of most burning issues that business owners face today:

- A lack of business skills, this is because of a poor education system and little or no culture of entrepreneurship;
- A lack of finance, financial institutions will only lend money to low-risk clients and the cost of banking is high;
- High costs, the cost of raw materials and telecommunications is high;
- Poor skills of employees, the government skills development system is not assisting SMEs;
- Bargaining councils, they have become huge conspiracies in which smaller businesses are crushed; the CCMA, time is wasted because employees can take their employers there for the smallest whim;
- The black economic empowerment; businesses are still confused by the multitude of criteria set out in the codes.
- Many owners also pay consultants huge sums of money to obtain ratings they do not yet require;
- Crime;
- Stock theft as an example; obviously has a negative effect on some of the SMEs;
- Exposure; the business owners do not portray themselves well.

5. Challenges faced by SME,s

The following concerns about the growth and development of SMEs were identified by [21;22 &31]

- Ownership constraints are particularly severe for entrepreneurs (especially women) in rural areas.
- Low-wage competition is discouraged by legislation, thereby discouraging labour intensive activity.
- There is a small customer base.
- Interest rates are high and there is limited or no access to capital.
- There are insufficient government contracts and weak support programmes.
- International trade is limited.
- Plans and technology are outdated and management skills are inadequate resulting in poor management.

6. Methodology

6.1 *Research approach and design*

Quantitative approach method was used to collect data for the study. A quantitative research is an enquiry into an identified problem, measured with numbers, and analysed using statistical techniques. The goal is to determine whether the predictive generalizations of a theory hold true. Much research in the engineering and management sphere involve asking and obtaining answers to questions through conducting surveys of people by use of structured questionnaires, interviews and observations. The study utilised questionnaires to collect data and answer the objective of the study which was to investigate the hindrances of implementation of health and safety among SME's in the Gauteng Province of South Africa. The study was carried out in Gauteng Province of Republic of South Africa, specifically on the Johannesburg areas, on small and medium enterprises (SME's) contractors. The target population were the owners and managers of SME's in Johannesburg Metropolitan Municipality. The reason for choosing owners and managers was that, they can offer useful information on the occupational health and safety challenges among SME's contractors in the construction industry of South Africa.

6.2 Analysis

In this study, the analysis employed simple statistical methodology, which is descriptive statistics (mean, mode, median, number, percentage, range, standard deviations). Respondent were required to respond to question based on the five point likert scale. The Likert scale was used because it allows a range of responses to be generated including neutral answers and does not force a decision as in the case of "yes" or "no" type of questions. The mean item score was adopted to rank the factors from highest to lowest. The Mean Item Score (MIS) is expressed and calculated for each item as follows:

$$\textbf{MIS} = \frac{1n1 + 2n2 + 3n3 + 4n4 + 5n5}{\sum N}$$

Where;
n1 = number of respondents for strongly disagree
n2 = number of respondents for disagree
n3 = number of respondents for neutral
n4 = number of respondents for agree
n5 = number of respondents for strongly agree
N = Total number of respondents

7. Findings and discussions

7.1 Level of implementation of OHS in SME's contractors

Respondents were asked to state the level of implementation of OHS among the SME's, about 33% of the responded felt that it was practiced between 60-70%, 31% of the respondent believed that it was practiced between 80-90%, 24% between the range of 30-50% and 12% between the range of 90-100%.

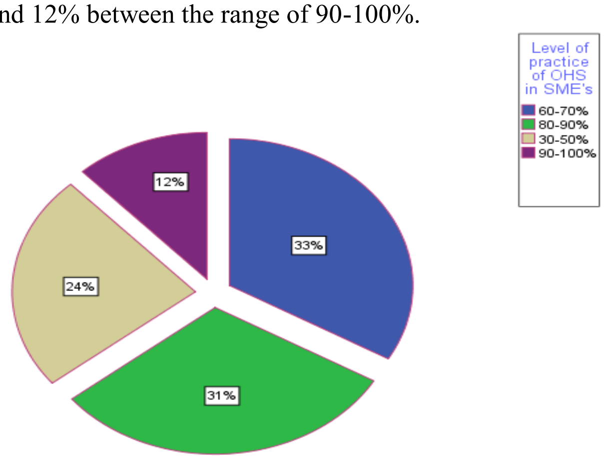

Figure 7: Level of implementation of OHS in SME'S

7.2 Hindrances of OHS implementation by SME's

Respondent were asked to rank the factors that hinder the success implementation of OHS among SME's contractors, The responded rank lack of regular inspections and audits the highest with a MIS =4.40 and STD=.964; poor management/supervision/information flow; Material and components was ranked 2 with a MIS=4.31 and STD=0.924 and 1.047 respectively; lack of management commitment was ranked 3 with MIS=4.29 and STD=0.970; Equipment and tools was ranked 4 with and MIS=4.21 and STD =0.976; lack of communication between workers was ranked 5th with MIS=4.17 and STD 0.853; poor employees involvement was ranked 6th with MIS=4.14 and STD=1.049; lack of training and risk education was ranked 7th, with MIS=4.12 and STD=1.109; lack of skilled workforce was ranked 8 with MIS=4.10 and STD=0.983; work area access was ranked 9th with MIS=4.02 and STD=1.024; poor work/jobsite conditions ranked 10th with MIS=3.98 and STD=0.924; subcontractors involvement was ranked 11 with MIS=3.95 and STD=1.147; lack of incentive for good performance was ranked 12 with MIS=3.93 and STD=1.135; investigations and risk assessments was ranked 13th with MIS=3.83 and STD=1.208.

Table 1: Implementation level

Descriptive Statistics	MIS	Std. Deviation	Rank
Lack of regular inspections and audits	4.40	.964	1
Poor management/supervision/information flow	4.31	.924	2

Material and components	4.31	1.047	2
Lack of management commitment	4.29	.970	3
Equipment and tools	4.21	.976	4
Lack of good communication between workers	4.17	.853	5
Poor employees involvement	4.14	1.049	6
Lack of training and risk education	4.12	1.109	7
Lack of skilled workforce	4.10	.983	8
Work area access	4.02	1.024	9
Poor work/jobsite conditions	3.98	.924	10
Subcontractors involvement	3.95	1.147	11
Incentive for good performance	3.93	1.135	12
Investigations and risk assessments	3.83	1.208	13

Table 2 below shows the benefit of Occupational health and safety implementation in SME's contractor. Where the responded ranked 1st Reduce lost times spent on injuries with MIS=4.26; STD=0.828; Avoid threat of legal action or prosecution and ; Increase productivity was ranked 2 with MIS=4.19 and STD=0.804; 0.634 respectively; Improve quality work was ranked no.3 with MIS=4.17, STD=0.537; Implementation contributes contractors growth and Improve relationship between contractors and workers was ranked 4th with MIS=4.05 and STD=0.764 &0.795 respectively; Reduced claims was ranked 5 with MIS=4.02, STD=0.924; Reduces accidents was ranked 6 with MIS=4.00 and STD=0.883; Motivate health workers; Improved employee job satisfaction and Reduced rework were ranked 7 with MIS=3.95 and STD=0.936 and 0.987 respectively; Better chances in bidding process was ranked 8th with MIS=3.90 and STD=0.983; Improves schedule performance was ranked 9 with MIS=3.74 and STD=0.828 and Lower employee turnover was ranked 10th with MIS=3.33 and STD=1.141

Table 7.2: Benefits of OHS

Benefits	**MIS**	**Std. Deviation**	**Rank**
Reduce lost times spent on injuries and properly loss	4.26	.828	1
Avoid threat of legal action or prosecution	4.19	.804	2
Increase productivity	4.19	.634	2
Improve quality work	4.17	.537	3
Implementation contributes contractors growth	4.05	.764	4
Improve relationship between contractors and workers	4.05	.795	4
Reduced claims	4.02	.924	5
Reduces accidents	4.00	.883	6
Motivate health workers	3.95	.936	7
Improved employee job satisfaction	3.95	.936	7
Reduced rework	3.95	.987	7
Better chances in bidding process	3.90	.983	8
Improves schedule performance	3.74	.828	9
Lower employee turnover	3.33	1.141	10

8. Conclusion

The Findings of this study presented the factors that hinder the success implementation of OHS among SME,s to be lack of communication, lack of management commitment lack of regular inspections and audits; poor management/supervision/information flow; lack of management commitment; Equipment and tools; lack of *communication* between workers; poor employees involvement; lack of training and risk education; lack of skilled workforce; poor work/jobsite conditions. Furthermore, if the challenges could be addressed appropriate and effectively result could manifest such as increased productivity; improve quality work; contractors growth and reduced claims; reduced accidents; reduced rework; improved schedule performance. Management and leadership at all levels are therefore encourage to improve construction OH&S in South Africa among SME's. Moreover, occupational health and safety of the workers is not negotiable, is all pervasive, increases productivity, and leads to better performance, improve the company image, reduced claims and accidents also reduce lost times spent on injuries.

9. Recommendations

The concept of OHS implementation must be emphasized by the client and the consulting team by way of having occasional not once off, a major workshop to be held three times in a year, to increase the awareness and the seriousness of the implementation of OHS.

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Methodology for assessing the comfort of an urban environment in terms of availability analyzing

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Abstract

Creating a safe and comfortable environment, developing a human, is a priority of urban development. One of the important stages of the solution to such a problem is the actualization of the regulatory base in the field of city-building, which should lay the principles of a city, developing a human and promoting better health.
The work shows the feasibility for quantitative analysis of safety and comfortable spatial environment when creating general plans of cities and their territorial entities. So, using the method of calculating the integral index of spatial-temporal accessibility of objects that implement the functions of the city, we suggest performing a comprehensive quantitative evaluation of planning decisions in terms of placing of socially significant objects. A key prerequisite for the calculation of this index was the inclusion of the time parameter provided to a person to realize his/her rational needs. This approach is based on the principles of creating biosphere compatible cities that develop a person, and allows not only more fully appreciate the quality of urban planning decisions, but also to consider the interests of groups with different mobility.
As an example, we determined the level of implementation of the city functions “Knowledge” (components - pre-school and general education) and “Entertainment and leisure” (component – recreation open urban green spaces) for different groups in a new micro-district in Orel. The calculation of the indicator was carried out for children aged 3-4 years, 7-8 years, healthy young people, people in old age and residents with disorders of the musculoskeletal system. For the latter, the obtained values differ from the maximum possible. The analysis noted the insufficient capacity of educational institutions, reflecting a defective personal availability.

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Keywords: aged people, built environment, open space, people with disabilities, urban planning;

Introduction

Creating a safe and comfortable environment, developing a human, is a priority of urban development. Along with the development and improvement of general plans of cities and districts it is necessary to include activities to balance the results of anthropogenic activities and the life potential increase of the Biosphere. One of the important stages of the solution to such a problem is the actualization of the regulatory base in the field of town-building, which, according to the academician V. A. Il'ichev and his followers, should lay the principles of a biosphere compatible city, developing a human [1,2].

Cities, being developed in accordance with the statements of this concept are characterized, in the first place, with a level of a symbiotic relationship with the biosphere and the degree of implementation of opportunities for human development. The latter, in turn, is determined by infrastructure, the quality of the functional organization of the territory, safe and comfortable ways of moving. Because of the complexity and multidimensionality of the concept of

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human potential for its quantitative determination from these positions the integral index ξ, which reflects the realization of the city functions, is introduced. In this case, the functions of the city according to the structure proposed in [1-3] are sustenance, entertainment and recreation, the organization of the structures of power, mercy, knowledge, creative realization of human needs, strengthening its relationship with nature.

In the first approximation, the quantitative analysis of the levels of implementation of city functions is suggested being conducted on the basis of statistical data for the regions, taking as criteria the average or normative values [3, 4]. Using the named index it is possible to assess the safety, accessibility and comfort of the various facilities, e.g. transport infrastructure [5, 6]. Here, by calculation the coefficients of the implementation and availability of the city functions based on the analysis of the state of the production environment of car service stations were obtained.

The article [7] shows the calculation of the level of implementation of the education functions based on qualitative and quantitative assessment of the indices characterizing the degree of accessibility, security and comfort of the educational environment in universities. The paper [8] gave the recommendations to the quantitative evaluation of urban planning decisions of new micro-districts based on the concept of biosphere compatibility. The analysis of biosphere compatibility and level of implementation of the city functions in relation to the needs of the disabled population is given in the articles [9-11]. Here, without an analysis of the territorial accessibility, attention is paid to functional planning factors determining the accessibility of facilities for groups of people with limited moving abilities.

A more detailed assessment of planning solutions of the micro-districts with the help of this index is relevant for objects of everyday services. A key requirement to their location is to provide pedestrian accessibility which reduces the time for obtaining the necessary services and limits the use of road transport. It assists to person's healthy way of life and his or her social integration, and has a positive effect on the safety and availability of transportation, acoustic comfort, air quality and soil in the residential neighborhood [12]. Besides, it is impossible not to agree with the author of the article [13] that the orientation of urban quarters, micro-districts to ensure short distances between facilities of daily service and housing, jobs will make the activity more sustainable in terms of its spatial-economic transformation. Specific quantitative indices mainly determining the capacity and service radius are regulated for such objects (Fig. 1).

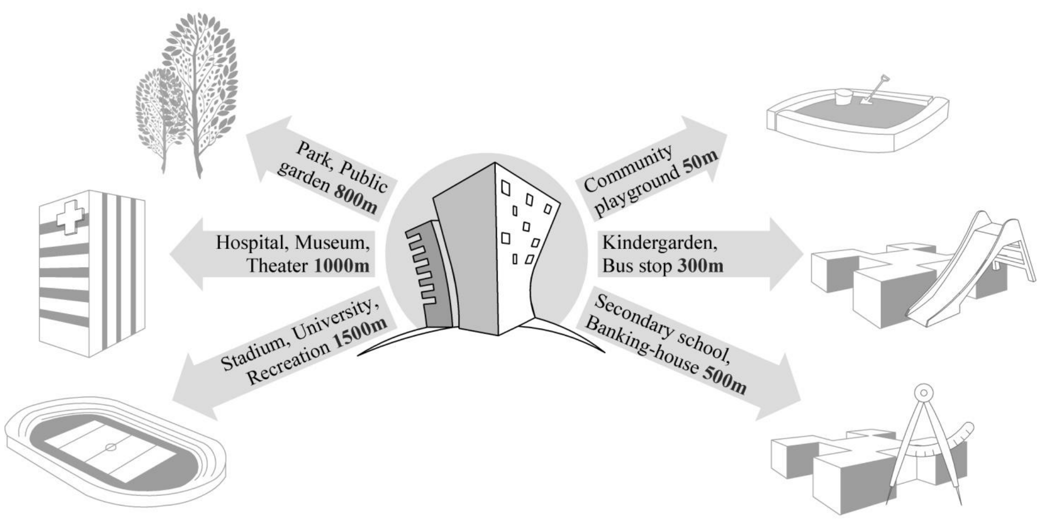

Fig. 1 Some recommended distances from places of residence to public buildings and structures

A disadvantage of the assignment of the distances to constant numerical values is the inability to take into account the characteristics of movement of different categories of the population fully. In this context, in order to quantify the walking availability it is recommended to measure distance between the objects of the infrastructure with the time needed to meet rational human needs [1]. Thus, evaluation of the safety and comfort of the urban environment in the specified statement using the index ξ will allow to consider interests of children and the elderly, pregnant women, persons with disabilities and others.

This approach was applied in determining the spatial and temporal availability of educational facilities [14]. In the

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present work it is proposed to extend the developed methodology to assess the availability of urban open spaces designed for walking with children, communication, sports, recreation for residents with special movement abilities. Unlike most of European countries, Canada [15-17] and the United States of America, in Russia the availability of public parks and parks planning areas is estimated by the time of their accessibility by public transport [18]. However, increasing the radius of accessibility to a few kilometers will lead to the need to organize a large number of parking spaces and increase of environmental load on the territory adjacent to the park.

Methods

The method of calculating the implementation index of the city functions (i=1..7) in the socially important objects at the level of planning districts is reduced to determining the integral index of the territorial-personal availability ξ_i:

$$\xi_i = \sum_{j=1}^{m} N_j \xi_{i,j} / N, \tag{1}$$

where N_j, N – respectively, the population of the j site and the district under consideration as a whole. This division of the planning area on m (number) of j sites can be done by separating residential groups or radial zones of accessibility.

Here $\xi_{i,j}$ is an indicator of the implementation of the i city function for the j site of a residential zone and an index of territorial (pedestrian) or space-time accessibility for residents of this area. It is defined by the ratio of time $\bar{t}_i$ spent by a person of a certain group of mobility to overcome the comfortable distance $\bar{S}_i$ to the object, to the time actually spent $t_{i,j}$:

$$\xi_{i,j} = D_i \cdot \bar{t}_i / t_{i,j} \text{ или } \xi_{i,j} = D_i \cdot \bar{S}_i / S_{i,j}, \tag{2}$$

where D_i is the coefficient that indicates the proportion of the population with the possibility of obtaining service of the i city function P_i , in the total number of inhabitants $\overline{P}_i$ of the territorial:

$$D_i = P_i / \overline{P}_i, \; D_i \leq 1. \tag{3}$$

Then the values $\xi_{i,j}$ can be equal to:

– within the service area of the facility at a distance not exceeding the maximum comfortable distance, and with sufficient capacity object – ($\xi_{i,j} = 1$);

– on the territory located outside of the comfortable safe distance – ($0 < \xi_{i,j} < 1$).

In Eq. 2 $S_{i,j}$ – the actual distance between the object that implements the i city function and the j site is determined by the length of the trajectory path, taking into account its non-linearity:

$$S_{i,j} = R_{i,j} \cdot K_{i,j}, \tag{4}$$

where the nonlinearity coefficient of the pedestrian connection will be equal to:

$$K_{i,j} = S_{i,j} / R_{i,j}, \tag{5}$$

where $R_{i,j}$ is the shortest distance between the object and the j site, which is the actual radius of the object accessibility.

Included in Eq. 2 $\bar{S}_i$ the parameter defines a comfortable distance which is to overcome in time $\bar{t}_i$:

$$\bar{S}_i = \bar{t}_i \cdot V, \tag{6}$$

where V is the average speed of a man with a certain mobility, depending on age and health state.

Table 1 presents the values of comfortable distances defined by values of the average speed of pedestrians moving rapidly or calmly in the autumn-winter period (according to the Leningrad scientific research laboratory of forensic examinations and [19]).

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Table 1. The distances covered by pedestrians with different movement speed for the estimated time

Pedestrians' age or their moving abilities	Calm pace				Rapid pace			
	V, m/min	Distance S, m			V, m/min	Distance S, m		
		5 min	7 min	10 min		5 min	7 min	10 min
3-4 years	51.0	255.0	357.0	510.0	72.0	360.0	504.0	720.0
7-8 years	69.3	346.5	485.1	693.0	88.8	444.0	621.6	888.0
21-25 years	82.2	410.9	575.2	821.7	106.3	531.5	744.1	1063.0
over 70 years	48.3	241.5	338.1	483.0	65.6	328.0	459.2	656.0
with a prosthetic leg[1]	51.0	255.0	357.0	510.0	67.5	337.5	472.5	675.0

In this formulation, the quantitative indicator of the safety and comfort of the urban space, and everyday pedestrian connections should be determined, in the first place, for socially significant objects, and it is suggested referring intra-district parks to these objects.

So, to assess the level of implementation of the function i=3 "Knowledge" it is recommended to take as initial data the distances corresponding to five minutes of walking rapidly. In addition, for pre-school educational institutions (i=31) we take the speed of pedestrians at the age of 3-4 years, and for educational institutions (i=32) – at the age of 7-8 years. The level of implementing the function i=2 "Entertainment and leisure" in relation to its component – leisure on the open urban green spaces (i=21) – can usefully be measured at a comfortable distance corresponding to the seven-minute walk at a slow pace. For residents with disorders of the musculoskeletal system a five minute walk is considered to be comfortable to overcome the distance.

As example we will perform a quantitative evaluation of planning decisions of district "Botanica" which is located in the Zavodskoi district of the city of Orel in the area between the floodplain of the Oka river and the railway line (Fig. 2). The area of the district is 40.2 hectares. The residential construction is represented by apartment houses with

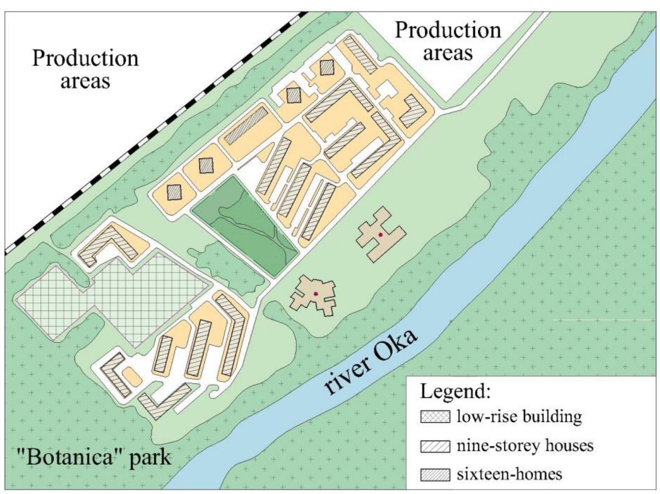


Fig. 2 The scheme of development of the micro-district "Botanica" in the city of Orel

a height of 9 and 16 floors. There is a park area of about 1.8 hectares in the center of the micro-district, and a

[1] the value of this speed is a guideline when assessing a comfortable distance for people with disorders of the musculoskeletal system

building of the preschool educational institution (PEI) for 280 seats and a secondary school (SS) for 550 seats in the south-eastern part. In the west the micro-district borders the Park "Botanica".

Results and Discussion

Fig. 3 graphically presents comfortable distances to the facilities for pre-school and general education and to the intra-district park for people with different moving abilities.

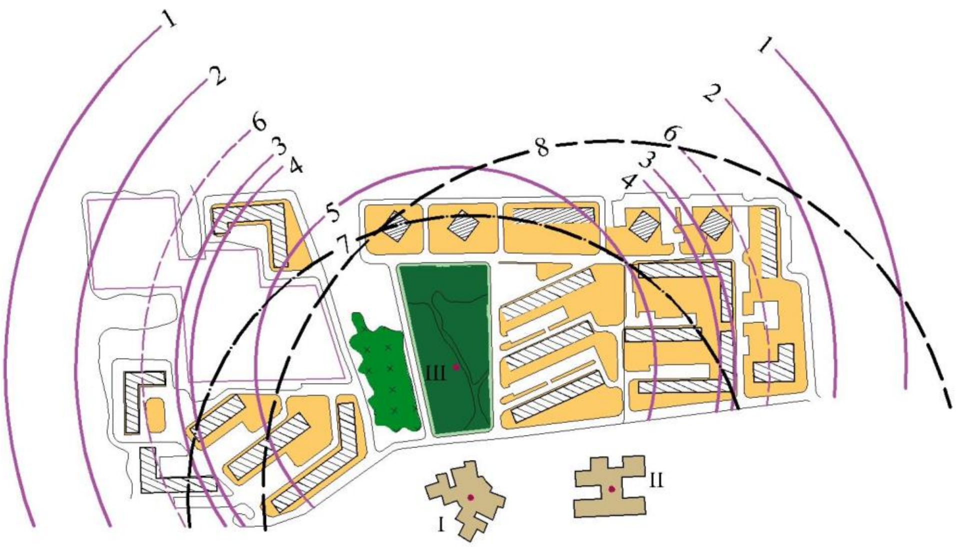


Fig. 3 – The radii of the accessibility of pre-school educational institution I, secondary school II and the intra-district park III in the micro-district "Botanica", corresponding to comfortable distances: 1 - for healthy people aged 21-25 years, 2,8 – 7-8 years, 3,7 – 3-4 years, 4 – over 70 years, 5 – for people with disorders of the musculoskeletal system, 6 - for all population groups, in accordance with [16]

As it can be seen from Fig. 3, the radii of the pedestrian accessibility of socially significant objects do not fully cover the territory of the considered micro-district. So, apartment buildings in the north-western and eastern parts of the micro-district are located from educational facilities at distances greater than comfort values. In this regard, and also due to the insufficient capacity of educational institutions, indicators of implementation of preschool and school education in the district are $\xi_{31} = 0.80$ и $\xi_{32} = 0.67$ [14], respectively.

Spatial environment of the everyday pedestrian connections is fully safe and comfortable only for healthy young people. A safe and comfortable environment for persons with disorders of the musculoskeletal system, the elderly and preschoolers is located in the central part. A more detailed analysis of spatial-temporal accessibility of the destination is given in the form of the scheme in Fig. 4. Here the boundaries of the comfortable distances to the adjacent park "Botanica" are marked. The figure shows the radial accessibility zones taking into account the non-linearity of pedestrian connections which as it is stated in the article [14], reduce the value of the desired indicator on the average on 9%.

The values of the indicators of the level of implementation of the function i=2 "Entertainment and leisure" in terms of its component i=21 "Leisure in urban open green spaces" in the micro-district "Botanica", defined by Eq. 1 for various population categories, are given in Table 2.

Table 2. Values of the index ξ_{21} for residents depending on the individual characteristics of movement

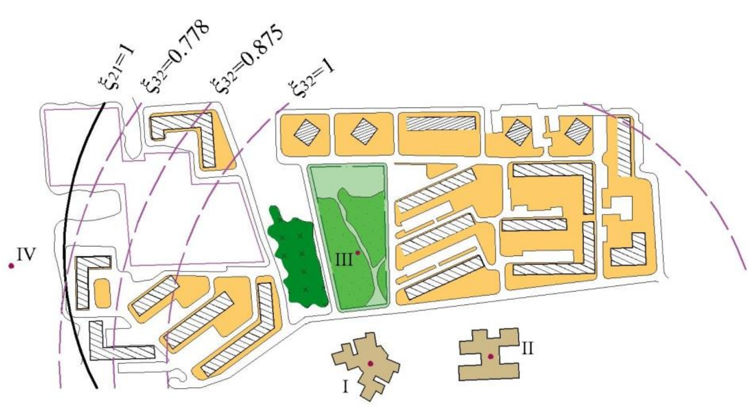
	Pedestrians' age or their moving abilities				
	21-25 years	7-8 years	3-4 years	over 70 years	with disorders of the musculoskeletal system
ξ_{21}	1.0	1.0	0.95	0.94	0.89

The results of a comprehensive assessment of spatial-temporal and personal accessibility of socially significant objects are considered as safety and comfort characteristics of the micro-district territory as well. According to the values of the integral index ξ it can be determined that the level of implementation of the city functions (the averaged value) within a residential district for children aged 3-4 years is $\xi_{2,3} = 0.875$, for children of primary school age is $\xi_{2,3} = 0.835$. The obtained values indicate low quality of planning decisions of the micro-district.

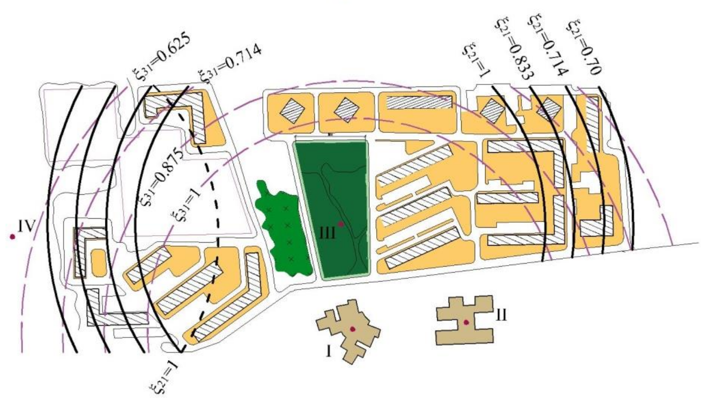
A more detailed analysis of the security and comfort of environment of everyday pedestrian connections may be adjusted by taking into account the quality of pedestrian communications between the object that implements the i city function, and place of residence (j site). This index depends on the following factors [14]:

- the number of crossings performed by a pedestrian in the same level of city streets with heavy traffic and driveways;
- length of the pedestrian way passing through the busy intra-quarter driveways;
- the availability of recreational areas and the distance between them;
- predicted thermal comfort [20-24];
- predicted level of acoustic pollution;
- aeration mode;
- insolation;
- the extent of landscaping, etc.

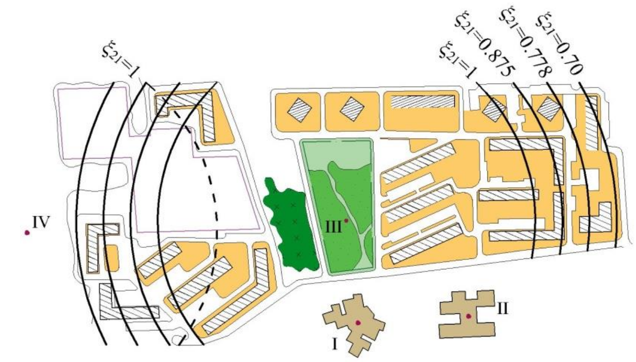
a)



b)



c)



d)

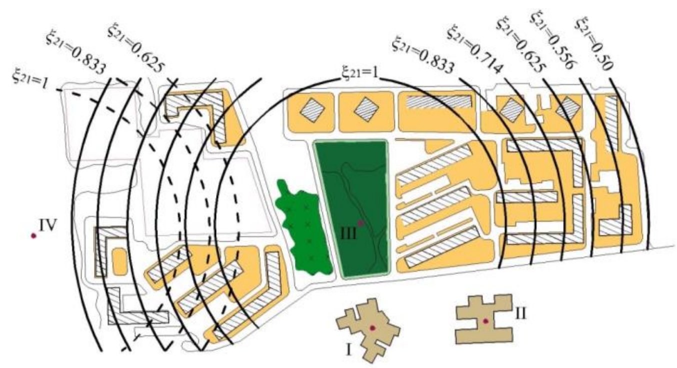


Fig. 4 – the division of the territory of the micro-district "Botanica" into the zones of space-time accessibility to the social facilities for children of school age (a), preschoolers (b), people of old age (c) persons with disorders of the musculoskeletal system (d)

Conclusions

For quantitative evaluation of the safety and comfort of the spatial environment in the analysis of its territorial personal accessibility it is proposed to use the integral index of the level of implementation of the city functions ξ_i. With regard to the location of the objects of everyday service this index will be an indicator of the effectiveness of urban design decisions from the standpoint of ensuring not only the functional adequacy of the territory, but the temporary accessibility.

The method for quantitative evaluation of planning decisions tested on socially significant objects of everyday services and recreational areas enables numerical justification of the location and capacity of new construction projects, and the feasibility of renovation of existing buildings, the organization of pedestrian paths and their improvement. Thus, the results of a comprehensive assessment of the quality of planning decisions of a new residential district in Orel have demonstrated a high degree of accessibility of the spatial environment for healthy young people. At the same time, for residents of old age, preschoolers, and disabled persons with disorders of the musculoskeletal system the space of everyday pedestrian connections is not fully safe and comfortable.

The graphic division of urban areas based on the values of the integral indicator of territorial and personal accessibility in the form of maps and schemes will allow to visualize the sufficiency of the levels implementation of the city functions. The results of the complex assessment of planning project areas and general plans performed with the help of this indicator will be useful for analyzing program effectiveness of long-term strategic planning in urban development.

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Preventing the Collapse of Reinforced Concrete (RC) Structures, and Support Work During Construction: A Support Work Manufacturer's Perceptions

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Abstract

In recent years, there have been a spate of collapses in South Africa, in terms of buildings, slabs, and support work. Given the current reality, a study was initiated to determine, inter alia, the importance of fifty-five factors relative to preventing the collapse of RC structures during construction, and the importance of thirty factors relative to optimum support work and formwork and the integrity of structures under construction.

The study reported on is based upon findings resulting from a self-administered survey of a temporary works designer and suppliers' staff that attended a workshop presented by the author.

The salient findings are as follows. 83.3% of the 55 factors are between near major to major / major importance, and 16.7% are between important to near major / near major importance relative to preventing the collapse of RC structures during construction. 83.3% of the 30 factors are between near major to major / major importance, and 16.7% are between important to near major / near major importance relative to optimum support work and formwork and the integrity of structures under construction.

Recommendations include that conformance to requirements is the key, that such requirements be scientifically evolved and communicated, a pre-requisite being that the required competencies exist, which can only be assured through a formal registration process, including that of contractors. Ideally, multi-stakeholder project H&S, quality, and risk plans should be evolved, and design and construction must be integrated. Then, general construction management and H&S planning must be a hallmark of all projects, and then optimum management and supervision to ensure execution of such planning.

Keywords: Collapses; Construction; Structures; Support work; Zero

1. Introduction

The report 'Construction Health & Safety Status & Recommendations' highlighted the considerable number of accidents, fatalities, and other injuries that occur in the South African construction industry [1]. The report cited the high-level of non-compliance with H&S legislative requirements, which is indicative of a deficiency of effective management and supervision of H&S on construction sites as well as planning from the inception / conception of projects within the context of project management. The report also cited a lack of sufficiently skilled, experienced, and knowledgeable persons to manage H&S on construction sites.

The spate of collapses in South Africa include the Pretoria North slab collapse, 1996, a notable collapse, which was 'flagged' in the 'Construction Health & Safety Status & Recommendations' report [1]. Then, more recently the Tongaat mall collapse in November 2013 [2] while under construction, highlighted the nature and extent of collapses involving reinforced concrete structures and support work. Furthermore, there have been a plethora of collapses between these two collapses, including the Injaka bridge collapse in July 1998 [3].

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Given the aforementioned, and the need to adopt a 'preventative' approach with respect to the problem, a study was conducted, the objectives being to, *inter alia*, determine the:

- Importance of fifty-five factors relative to preventing the collapse of RC structures during construction, and
- Importance of thirty factors relative to optimum support work and formwork and the integrity of structures under construction.

2. Review of the literature

2.1. Health and safety legislation and standards

The South African Construction Regulations constitute the primary regulations in terms of managing H&S in the construction industry [4].

Clients are required to, inter alia, prepare an H&S specification based on their baseline risk assessment (BRA), which is then provided to designers. They must then ensure that the designer takes the H&S specification into account during design, and that the designers carry out their duties in terms of Regulation 6 'Duties of designers'. Thereafter, clients must include the H&S specification in the tender documentation, which in theory should have been revised to include any relevant H&S information included in the designer report as discussed below.

Designers in turn are required to, inter alia: consider the H&S specification; submit a report to the client before tender stage that includes all the relevant H&S information about the design that may affect the pricing of the work, the geotechnical-science aspects, and the loading that the structure is designed to withstand; inform the client of any known or anticipated dangers or hazards relating to the construction work, and make available all relevant information required for the safe execution of the work upon being designed or when the design is changed; modify the design or make use of substitute materials where the design necessitates the use of dangerous procedures or materials hazardous to H&S, and consider hazards relating to subsequent maintenance of the structure and make provision in the design for that work to be performed to minimize the risk. To mitigate design originated hazards, requires hazard identification and risk assessment (HIRA) and appropriate responses, which process should be structured and documented. Furthermore, the designer report submitted to the client should schedule the residual hazards on projects, which in turn should be included in the 'revised' H&S specification included in the tender documentation.

Furthermore, the International Labour Office (ILO) [5] as early as 1992 recommended that designers should, inter alia: receive training in H&S; integrate the H&S of construction workers into the design and planning process, and not include anything in a design which would necessitate the use of dangerous structural or other procedures or hazardous materials which could be avoided by design modifications or by substitute materials.

The Construction Regulations [4] make provision for the appointment of Construction H&S Agents (CHSAs), and require the appointment of either part-time or full-time construction H&S Officers. However, the cidb industry report 'Construction Health & Safety Status & Recommendations' highlighted the need for professional registration of construction H&S practitioners due to, among other, the finding that there was a lack of competencies, and no formal registration process. The Council for the Built Environment (CBE) then mandated the South African Council for the Project and Construction Management Professions (SACPCMP) in terms of Act No.48 to register construction H&S professionals. This in turn led to the identification of three such categories of registration, namely Professional Construction Health and Safety Agent (Pr CHSA), Construction Health and Safety Manager (CHSM), and Construction Health and Safety Officer (CHSO).

The definition of temporary works includes any falsework, formwork, support work, scaffold, shoring, or any other temporary structure designed to provide support or means of access during construction work.

In terms of 'Duties of designer' Regulation 6(2), the designer of temporary works must ensure, inter alia, that: temporary works are designed such that they will support all anticipated vertical and lateral loads applied; the designs are done with close reference to the structural drawings, and the loads caused by the temporary works and any imposed loads are clearly indicated in the design.

In terms of 'Temporary works' Regulation 12, a contractor must: appoint a temporary works designer in writing to design, inspect, and approve temporary works before use; ensure that all temporary works are carried out under the supervision of a competent person appointed in writing; ensure that all temporary works are adequately erected, supported, braced, and maintained by a competent person so that they are capable of supporting all anticipated vertical and lateral loads, and that no additional loads are imposed on the structure; ensure that detailed activity specific drawings pertaining to the design of temporary works structures are kept on site; ensure that all persons required to

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erect, move, or dismantle temporary structures are trained and instructed to perform these operations safely; ensure that all equipment used for temporary structures are examined and checked for suitability before use by a competent person; ensure that all temporary works structures are inspected before, during, and after placement of concrete, after inclement weather, or any other imposed load and at least on a daily basis until the structure has been removed; ensure that no concrete may be cast till written authorisation has been given by the competent person, the temporary works structure is left in place until the concrete has acquired sufficient strength to support its own weight and any imposed load after casting the concrete, and the removal has been authorised by the competent person, the foundation conditions are capable of withstanding the loads of the temporary works structure and any imposed loads, temporary works drawings and any related document includes construction sequences and method statements, and temporary works drawings are approved by the temporary works designer before the erection of any temporary works.

The regulations referred to above can be summarised as follows in terms of issues: scientific design; coordination and integration of temporary with permanent works; consideration of the range of loads; foundation conditions; planning including method statements; competency; training; control, including inspections, and dismantling (striking).

2.2. Support work and formwork failures

The causes of support work and formwork failures are classified as enabling, triggering, and procedural [6]. Enabling causes are defined as events that contribute to the deficiencies in the design and construction of the support work, and include inadequate: design; soil foundation; cross-bracing, and design / construction of permanent structure. Triggering causes are events that initiate support work collapses, which are mostly and essentially the result of excessive loads exerted during construction. The loads are usually not expected, or underestimated at the design stage, and hence they trigger a local failure, which propagates a major collapse. Examples include: fierce winds; impact loads during concreting; vibration from equipment, and improper / premature removal of support work components. Procedural causes are procedural in nature and do not directly cause the support work to fail. However, the procedural errors are often hidden events that produce the enabling and trigger events. Furthermore, they are not easily extracted from failure reports due to a variety of reasons: inadequate review of support work design / construction; lack of inspection of support work during concreting, and inadequate communication between parties involved.

An investigation of falsework in the United Kingdom [7] concluded, inter alia: at all levels there is a lack of understanding of the fundamentals of stability of falsework and the basic principles involved; wind loading is rarely considered; contractors and specialist contractors predominately believe that the drawings and schemes prepared by proprietary suppliers are ‘designed’ and that they have incorporated in the ‘design’ all the correct assumptions necessary; there is a lack of checking of falsework designs prior to use, whether by suppliers, contractors or specialists, is seen to be an industry-wide problem, and there is a lack of falsework design experience in contracting, as the ‘design’ process has moved to suppliers.

A study conducted in Nigeria [8] determined the predominant reasons for building collapse include structural failure, poor supervision and workmanship, the use of sub-standard materials, lack of competency in construction techniques and supervision skills, faulty design, excessive loading, and adaptation and disdain for approved drawings.

The inquiry into the Coega bridge collapse in November 2003, determined, inter alia, that the scaffolding (sic) was unsafely designed, though there was a degree of safety [9].

2.3. The Tongaat mall collapse

A section of the Tongaat mall in South Africa, collapsed in November 2013 while under construction. A study conducted by Emuze, van Eeden, and Geminiani [10] summarised regulatory failures based upon a document analysis. Selected failures include: plans were not submitted to the local municipality’s development, applications, and approvals department; the principal contractor was unable to indicate the qualifications of responsible staff on site, and no consent was given by the construction H&S agent to remove formwork, props, or scaffolding on the day of the accident. Summarised causal factors include: plans rejected / failed four times; false work and formwork removed too soon; inadequate concrete strength; lapses in construction work and supervision; inadequate structural design, and inadequate steel reinforcing.

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3. Research

3.1. Research method and sample stratum

A survey was conducted at the inception of one of two workshops presented by the author to a regional entity of a major international temporary works designer and supplier using a self-administered questionnaire. The questionnaire consisted of eleven (11) questions, ten (10) of which were close-ended, and one (1) of which was open-ended. Three (3) of the close-ended questions were five-point Likert scale type questions, which also included an 'unsure' response option. The other close-ended questions were demographic data related. Twenty-three (23) Responses were received from the delegates and included in the analysis of the data.

The analysis of the data consisted of the calculation of descriptive statistics to depict the frequency distribution and central tendency of responses to fixed response questions to determine the degree of importance.

3.1. Research findings

Table 1 indicates the importance of 55 factors relative to preventing the collapse of RC structures during construction on a scale of 1 (limited) to 5 (major), and a mean score (MS) ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint score of 3.00, which indicates that in general the respondents perceive the factors as being of major as opposed to limited importance relative to preventing the collapse of RC structures during construction. It is also notable that 23 / 55 (41.8%) of all the MSs are > 4.20 ≤ 5.00, which indicates that the importance of the factors is between near major to major / major.

Of the 23 factors in the MSs range > 4.20 ≤ 5.00, the number per category are as follows: competency (8 No.); registration (3 No.); supervision (3 No.); design (3 No.); hazard and risk management (3 No.); quality management (2 No.), and project management (1 No.). Given the sample, it is notable that Temporary Works Designers' Temporary works design competencies is ranked first.

The remaining 32 / 55 (58.2%) factors' MSs are > 3.40 ≤ 4.20 - between important to near major / near major importance.

Table 1. Importance of factors relative to preventing the collapse of RC structures during construction.

Factor	Response (%)						MS	Rank
	Un-sure	Limited…………………………Major						
		1	2	3	4	5		
Temporary Works Designers' Temporary works design competencies	0.0	0.0	0.0	0.0	25.9	74.1	4.74	1
Registration of Engineering designers	0.0	0.0	0.0	3.7	22.2	74.1	4.70	2
Dedicated contractor supervision of the structure during construction	0.0	0.0	0.0	3.7	33.3	63.0	4.59	3
Close contractor supervision of the structure during construction	0.0	0.0	0.0	3.7	33.3	63.0	4.59	4
Temporary Works Designers' Structural competencies	0.0	0.0	3.7	3.7	22.2	70.4	4.59	5
Design of the permanent structure	0.0	0.0	3.8	11.5	7.7	76.9	4.58	6
Construction Management's Temporary works design competencies	0.0	0.0	0.0	11.1	25.9	63.0	4.52	7
H&S Agents' Temporary works design competencies	0.0	0.0	0.0	11.1	25.9	63.0	4.52	8
Construction Management's Structural competencies	0.0	0.0	0.0	7.4	33.3	59.3	4.52	9
Temporary works design	0.0	0.0	0.0	14.8	18.5	66.7	4.52	10
Integration of design and construction	0.0	0.0	0.0	11.1	25.9	63.0	4.52	11
Safe work procedures	0.0	0.0	0.0	8.3	33.3	58.3	4.50	12
Registration of Construction managers	0.0	0.0	3.7	7.4	25.9	63.0	4.48	13
Close engineering supervision of the structure during construction	3.7	0.0	0.0	11.1	29.6	55.6	4.46	14

Construction Management's Construction management competencies	0.0	0.0	0.0	11.1	33.3	55.6	4.44	15
Construction hazard identification and risk assessment	0.0	0.0	0.0	18.5	22.2	59.3	4.41	16
Project quality management	0.0	0.0	0.0	18.5	22.2	59.3	4.41	17
H&S Agents' Construction management competencies	0.0	0.0	11.1	0.0	25.9	63.0	4.41	18
H&S Agents' Structural competencies	0.0	0.0	11.1	0.0	29.6	59.3	4.37	19
Project H&S management	0.0	0.0	3.7	14.8	22.2	59.3	4.37	20
Design hazard identification and risk assessments	0.0	0.0	11.1	3.7	29.6	55.6	4.30	21
Registration of Project managers	0.0	0.0	0.0	22.2	25.9	51.9	4.30	22
Contractor quality management system	14.8	0.0	0.0	14.8	37.0	33.3	4.22	23
Contractor H&S management system	11.1	0.0	3.7	18.5	25.9	40.7	4.17	24
Contractor risk management system	7.4	0.0	0.0	18.5	40.7	33.3	4.16	25
H&S Specification	3.7	0.0	3.7	22.2	25.9	44.4	4.15	26
Project risk management	0.0	0.0	11.1	7.4	37.0	44.4	4.15	27
Temporary Works Designers' Construction management competencies	0.0	7.4	0.0	7.4	40.7	44.4	4.15	28
Contractor planning	11.1	0.0	0.0	14.8	48.1	25.9	4.13	29
Contractor project risk management plan	7.4	0.0	0.0	29.6	22.2	40.7	4.12	30
Construction Management's H&S competencies	0.0	3.7	0.0	25.9	22.2	48.1	4.11	31
H&S Agents' Project management competencies	0.0	0.0	14.8	7.4	29.6	48.1	4.11	32
Temporary Works Designers' Project management competencies	0.0	7.4	0.0	7.4	44.4	40.7	4.11	33
Design report submitted to the client in response to the H&S Specification	7.4	0.0	0.0	29.6	25.9	37.0	4.08	34
H&S Officers' H&S competencies	3.7	3.7	3.7	18.5	25.9	44.4	4.08	35
H&S Agents' H&S competencies	0.0	3.7	11.1	11.1	25.9	48.1	4.04	36
Temporary Works Designers' H&S competencies	0.0	11.1	0.0	11.1	33.3	44.4	4.00	37
H&S method statements	0.0	3.8	3.8	26.9	23.1	42.3	3.96	38
Contractor project quality plan	14.8	0.0	0.0	33.3	22.2	29.6	3.96	39
Project risk schedule	7.4	3.7	0.0	25.9	33.3	29.6	3.92	40
H&S Plan (contractors)	4.0	0.0	4.0	32.0	28.0	32.0	3.92	41
Construction method statements	4.2	4.2	4.2	29.2	16.7	41.7	3.91	42
H&S Officers' Temporary works design competencies	0.0	3.7	3.7	25.9	33.3	33.3	3.89	43
H&S Officers' Construction management competencies	0.0	7.4	0.0	25.9	29.6	37.0	3.89	44
H&S Officers' Structural competencies	3.7	3.7	7.4	22.2	33.3	29.6	3.81	45
H&S specification	7.7	3.8	0.0	34.6	26.9	26.9	3.79	46
3rd party review of the design of the permanent structure	0.0	0.0	25.9	11.1	22.2	40.7	3.78	47
H&S Plan (principal contractor)	8.0	4.0	4.0	32.0	24.0	28.0	3.74	48
Registration of H&S Officers	0.0	7.4	11.1	22.2	25.9	33.3	3.67	49
Construction Work Permit	11.1	14.8	7.4	11.1	18.5	37.0	3.63	50
Registration of Quantity surveyors	3.8	3.8	19.2	23.1	15.4	34.6	3.60	51
Registration of H&S Managers	0.0	14.8	7.4	18.5	25.9	33.3	3.56	52
Registration of H&S Agents	0.0	18.5	0.0	18.5	33.3	29.6	3.56	53
Municipal approval of plans	3.7	18.5	7.4	18.5	11.1	40.7	3.50	54
Registration of Architectural designers	0.0	14.8	7.4	25.9	22.2	29.6	3.44	55

Table 2 indicates the importance of 30 factors relative to optimum support work and formwork and the integrity of structures under construction on a scale of 1 (limited) to 5 (major), and a MS ranging between 1.00 and 5.00. It is notable that all the MSs are above the midpoint score of 3.00, which indicates that in general the respondents perceive the factors as being of major as opposed to limited importance relative to optimum support work and formwork and the integrity of structures under construction.

It is also notable that 25 / 30 (83.3%) of the MSs are > 4.20 ≤ 5.00, which indicates that the importance of the factors is between near major to major / major. Of the 9 factors in the upper part of the MS range > 4.20 ≤ 5.00 (> 4.60), the number per category are as follows: supervision (2 No.), competency (1 No.), and quality management (6 No.).

The remaining 5 / 30 (16.7%) factors' MSs are > 3.40 ≤ 4.20 - between important to near major / near major importance.

Table 2. Importance of factors relative to optimum support work and formwork and the integrity of structures under construction.

Factor	**Response (%)**						**MS**	**Rank**
	Un-sure	**Limited…………….…………Major**						
		1	**2**	**3**	**4**	**5**		
Pre-pour designer inspection (Support work and formwork)	0.0	0.0	0.0	3.8	7.7	88.5	4.85	1
Competencies of temporary works designer	0.0	0.0	0.0	3.7	14.8	81.5	4.78	2
Reconciliation of erected with design	0.0	0.0	0.0	0.0	30.8	69.2	4.69	3
Founding support work	0.0	0.0	0.0	0.0	34.6	65.4	4.65	4
Concrete strength upon striking of support work	0.0	0.0	0.0	0.0	34.6	65.4	4.65	5
Periodic inspections during erection	3.8	0.0	0.0	0.0	34.6	61.5	4.64	6
Concrete strength as per specified	3.8	0.0	0.0	3.8	26.9	65.4	4.64	7
QMS during design (Support work)	0.0	0.0	0.0	14.8	7.4	77.8	4.63	8
Back propping as per requirements	0.0	0.0	0.0	7.7	23.1	69.2	4.62	9
Dedicated support work supervision	3.8	0.0	0.0	3.8	30.8	61.5	4.60	10
Periodic inspections during pouring	3.8	0.0	0.0	3.8	30.8	61.5	4.60	11
Pre-pour designer inspection (Reinforcing steel)	7.7	0.0	0.0	7.7	23.1	61.5	4.58	12
Scientific support work design	3.7	0.0	0.0	3.7	33.3	59.3	4.58	13
Back propping layouts	0.0	0.0	0.0	7.7	26.9	65.4	4.58	14
Maintenance of components	0.0	0.0	0.0	7.7	30.8	61.5	4.54	15
Testing of components	3.8	0.0	0.0	7.7	30.8	57.7	4.52	16
Condition of components	3.8	0.0	0.0	7.7	30.8	57.7	4.52	17
QMS during construction	0.0	0.0	0.0	18.5	11.1	70.4	4.52	18
QMS during design (structure)	0.0	0.0	0.0	18.5	11.1	70.4	4.52	19
Circumspect loading of slabs and other elements during the back-propping period	0.0	0.0	0.0	12.0	28.0	60.0	4.48	20
Compaction of concrete	3.8	0.0	0.0	3.8	42.3	50.0	4.48	21
Sound structural design	11.5	0.0	7.7	7.7	7.7	65.4	4.48	22
Safe work procedures	4.0	0.0	0.0	8.0	40.0	48.0	4.42	23
Periodic inspections during striking	3.8	0.0	0.0	11.5	34.6	50.0	4.40	24
Periodic inspections during the back-propping period	3.8	0.0	0.0	11.5	34.6	50.0	4.40	25
Construction method statements	3.7	3.7	3.7	25.9	25.9	37.0	3.92	26
H&S Plan (Contractors)	7.4	3.7	3.7	40.7	7.4	37.0	3.76	27
H&S Management System	11.5	3.8	11.5	19.2	26.9	26.9	3.70	28
H&S Plan (Principal Contractor)	7.4	3.7	3.7	40.7	18.5	25.9	3.64	29
H&S method statements	11.5	3.8	7.7	34.6	15.4	26.9	3.61	30

4. Conclusions

Given the importance of factors in terms of preventing the collapse of RC structures during construction, it can be concluded that the requisite 'cocktail' of factors must be in place and to an optimum extent. Competencies, design, registration of built environment professionals, HIRAs, supervision, quality management, H&S management, risk management, planning and H&S planning in various forms, integration of design and construction, and the construction work permit, are all important as clusters or individually relative to preventing the collapse of RC structures during construction.

Similarly, given the importance of factors relative to optimum support work and formwork and the integrity of structures under construction, it can be concluded that the requisite 'cocktail' of factors must be in place and to an optimum extent. Quality management, competencies, supervision; a range of support work aspects, inspections, circumspect loading, H&S management, planning and H&S planning in various forms, and conformance to requirements, are all important as clusters or individually relative to optimum support work and formwork and the integrity of structures under construction.

5. Recommendations

Ultimately, conformance to requirements is the key, which includes, among other, municipal approval of building plans, and the construction work permit. However, a pre-requisite for conformance to requirements is that many of the requirements should be scientifically evolved and communicated. However, in parallel, the required competencies must exist to enable such evolution. Competencies in turn can only be assured through a formal registration process such as that required by the six South African built environment councils. Registration of contractors should interrogate H&S, quality, and risk management systems and practices. Clearly, contractors should also be pre-qualified in terms of H&S, quality, and risk management systems and practices.

Ideally, multi-stakeholder project H&S, quality, and risk plans should be evolved. Design and construction must be integrated and the 'grey areas' relative to achieving same must be addressed. Then, general construction management and H&S planning must be a hallmark of all projects.

Management and supervision are critical, as both planning and execution are important.

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Probabilistic risk appraisal and mitigation of critical infrastructures for seismic extreme events

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Abstract

The importance and the interdependencies of critical infrastructures such as power and water supply, communications, and healthcare is increasing continuously and constantly. Most of the vital services for the private and the public sectors depend on the continuous performance of critical infrastructures. However, the last decades' extreme events reveal a significant gap between the preparedness of critical infrastructures and the actual risk that those infrastructures are exposed to in case of seismic event. In this research a methodology is developed to appraise and mitigate the risk that critical infrastructures are exposed to in case of seismic events. The proposed method is designated also to act as decision support tool for the selection of the most advantageous strategy to reduce the risk expectancy for extreme seismic events.
A Probabilistic Seismic Hazard Analysis (PSHA) approach is used in order to reflect a variety of possible seismic scenarios and overcome the uncertainties regarding to the timing, the location, and the magnitude of an earthquake. The seismic vulnerability of different components is evaluated by adjusted fragility curves and Fault-Tree-Analysis. The seismic risk function, that expresses the expected risk of the system for a given ground motion intensity, is derived according to the occurrence probabilities of the earthquake, the seismic vulnerability of different components, and the expected consequences.
This paper introduces the developed methodology and demonstrates the key steps through a two case studies of oil pumping plant and oil tank farm. The pumping plant case study demonstrates the development of the risk function and examines the contribution of a possible mitigation strategy on the overall risk expectancy. The oil tank farm case demonstrates a derivation of an exclusive fragility function for critical infrastructures facility.
This methodology provides novel analytical and decision-support tool that integrates between the components adjusted fragility curves in the risk assessment and the consequent mitigation step; the optimal mitigation strategy is derived from the fragility parameters reflection on the total risk function.

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Keyword : Critical infrastructure; Risk appraisal; Risk Mitigation; Fragility curve; Earthquakes;

1. INTRODUCTION

Critical Infrastructures (CI) play a crucial role in the normal performance of the economy and society. Over the last decades the amount and the variety of critical infrastructures grew rapidly, and the interdependency between them increased constantly; consequently, more and more essential services depend on the continuous performance of one, two or even more critical infrastructures such as power, water supply, communications, etc.

As was observed in previous studies, there is a significant gap between the stability and the preparedness level of CIs for seismic events and the actual damage that those facilities are exposed to in a case of a seismic event [1]-[3]. The consequences of the latest seismic events emphasize the importance to mitigate the seismic risk by increasing the preparedness of CIs and ensuring reliable and robust performance on a continuous basis, particularly during and after

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the occurrence of extreme events. Implemented mitigation strategy is derived accordingly to the financial limitation and depends on decision makers' policy. Therefore, at first, in order to clarify the actual risk that CIs are exposed to in case of seismic event the risk should be quantified. Subsequently, in case the risk is not acceptable, different mitigation strategies must be examined in order to select the most optimal strategy, respectively to the financial feasibility.

The major objective of this research is to develop a probabilistic methodology that examines the preparedness of critical infrastructures through an appraisal of the risk that CIs are exposed in case of seismic events and provide a decision support tool for risk mitigation. Prior methodologies for risk appraisal [4]-[6] presented procedures that offer tools such as fragility curves, fault tree analysis, logic tree in order to appraise the risk of different components. Those methodologies presented tools to appraise the risk for existing generic infrastructures based on empiric data. However, those studies didn't examine different mitigation strategies and their effectiveness on the risk reduction and didn't conclude to the optimal strategy. Moreover, those methodologies are mainly used in order to appraise the risk as a result of a specific earthquake event.

This methodology is intended to expand prior risk appraisal tools such as fragility curve and fault tree analysis and implement them as a decision support tool for policy makers. This methodology intended to quantify the seismic risk by a probabilistic seismic analysis of a variety of possible seismic scenarios and examine different mitigation strategies in order to conclude the most optimal mitigation strategy under the given financial constraints.

2. Methodology

2.1 Seismic Hazards Identification

The seismic threat for each CI's component is identified according to the location of the facility according probabilistic seismic hazard analysis (PSHA) as presented by [7]. The PSHA approach is intended to consider all possible scenarios according to geological data about the possible earthquake sources, and the probability of magnitude and intensity occurrence that is associated with those events. The PSHA approach requires ground-motion attenuation models that estimate the expected ground-motions at a given site as a result of different intensity and location earthquakes, several studies offer attenuation models for different location and regions [8], [9]. This step yields an Annual Rate of Exceedance curve (PE_A) as a function of a given ground motion intensity measure (IM); when in most cases, for above-ground structures the IM is expressed in term of peak ground acceleration (PGA) [10]-[12].

2.2 System's Seismic Vulnerability

In this step, the expected damage state as a result of a seismic event is formulated in terms of fragility curve. The fragility curve expresses the probability of reaching or exceeding certain damage states for a given level of IM [13]-[16]. This function is fully defined by determination of two parameters: median capacity of the component to resist the damage state (θ) and standard deviation of the capacity (β).

$$P[DS \geq ds|IM = x] = \Phi\left(\frac{ln(x/\theta_{ds})}{\beta_{ds}}\right) ; ds \in \{1,2, \dots N_D\} \quad (1)$$

Eq. 1 expresses a formulation of a fragility function. When P stands for a conditional probability of being at or exceeding a particular Damage State (DS) for a given seismic intensity x defined by the earthquake Intensity Measure (IM).

Where,

DS	Uncertain damage state of a particular component. {0,1,... Nn}
ds	A particular value of DS
N_D	Number of possible damage states
IM	Uncertain excitation, the ground motion intensity measure (i.e. PGA, PGD, or PGV)
x	A particular value of IM
Φ	Standard cumulative normal distribution function.
θ_{ds}	The median capacity of the component to resist damage state ds measured in terms of IM

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β_{ds} Logarithmic standard deviation of the uncertain capacity of the component to resist damage state ds

In this step, the fragility parameters can be yield on the existing values that are available for generic components based on prior studies [4], [6], [12], [17]. However, in the case of a unique system or component, it is preferable to develop exclusive values for the system in accordance to the fragility of the sub-component.

2.3 Damage Assessment due to seismic Extreme Events for different components

This step associates a damage ratio (DR_i) with each damage state; the DR_i expresses the percentage of the total replacement value of a component corresponding to damage state i. Subsequently, since the damage ratio is associated directly to the damage state, the expectant damage ratio of a component (DR_c) can be calculated as follows:

$$DR_c = \sum_{ds} DR_i * P(ds_i|IM) \tag{2}$$

Where

DR_i	Damage rate of the damage state i
$P(ds_i \|IM)$	Conditional probability of being in a certain damage state i for a given IM

Furthermore, the expected repair cost (RC_c) of the component for a given IM can be calculated regarding to the replacement value (RV_c); when the RV_c expresses the total replacement cost of the component. Thus, one can calculate the expected direct damage of the component for any given IM as follows:

$$RC_c(IM) = RV_c \cdot \sum_{ds} DR_i \cdot P(ds_i|IM) = DR_c * RV_c \tag{3}$$

2.4 Risk Appraisal according to expected damage

The product of this step is a seismic risk curve that presents the expected annual risk for any given value of IM. Since risk represents the potential impact and loss and it is defined as the product of the occurrence probability and the expected consequences, this curve is constructed by multiplying the annual rate of exceedance curve with the direct damage curve by matching between the PGA values in both curves and links the expected consequence and its probability to occur. This matching produces a curve that correlated between the expected damage in terms of annual expectancy of risk and the PGA.

$$R_A(IM) = RC_c(IM) \cdot PE_A(IM) \tag{4}$$

Where

$R_A(IM)$	Annual risk for a given IM
$RC_c(IM)$	Replacement cost of the component for a given IM
$PE_A(IM)$	Annual rate of exceedance of a given IM

2.5 Risk Mitigation

In this step, different mitigation strategies are examined in order to predict the effectiveness of the mitigation strategy on the preparedness level of the CIs by quantifying the reduction of risk followed by implementation of each strategy. Each examined mitigation strategy has different effects on the robustness and the resilience of the system which is reflected in different parameters of the fragility curve; those changes will effect on the level of risk. Subsequently, the optimal strategy is selected according to the level of reduction of risk and economic considerations.

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3. Methodology implementation: Case study 1

This chapter demonstrates a conceptual implementation of the methodology through a case study of an oil pumping plant (PP). Pumping plants serve to maintain the flow of oil across pipeline system. They are located at certain intervals along the pipeline network to ensure the transport over long distances and around the storage facilities when the pressure must be increased due to friction losses. In addition, Pumping is also required to transport oil uphill wherever this is required by topographic conditions.

The annual rate of exceedance curve depends on the specific location of the facility. Therefore, in this case, the pumping plant is assumed to be located in Beer-Sheva, Israel. A simplified annual rate of exceedance curve (Figure 1) was derived based on the values that were published by the Geophysical Institute of Israel report [18]. In this report, the attenuation is based on the model of [19] which has a good correlation to the Middle-East seismic patterns. This attenuation model considers a sufficient range of magnitudes (4-8.5) and allows considering the effects of weak seismic areas. Moreover, this attenuation considers main parameters of site effect such as: Magnitude (M), distance from rupture (R), fault mechanism, and soil stiffness.

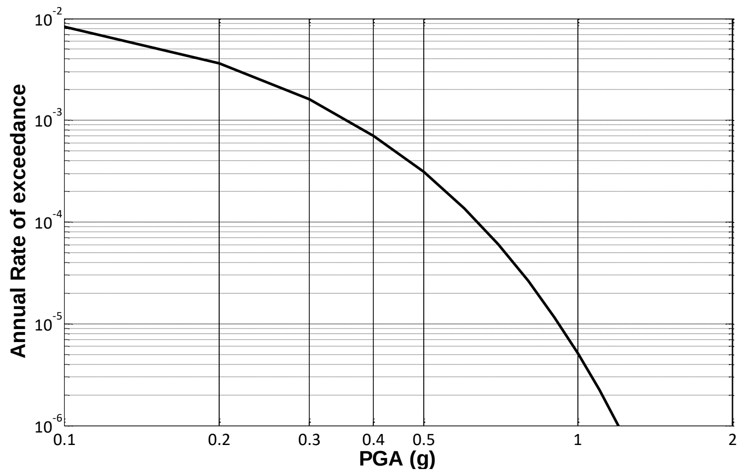

Figure 1 - Annual rate of exceedance curve for west Beer-Sheva region

According to [6] the failure of a pumping plant is most likely to occur as a result of damage to one of its main sub-components: the building, one or more pumps, electrical equipment, and electric power and backup systems.

In this case, the fragility parameters are based on the values proposed by [4] for unanchored pumping plant (Figure 2), the damage ratio of the tank is based on the estimate damage ratio that proposed by [4], and the replacement cost for a pumping plant is estimated at 1M US$.

Table 1.Damage states description and parameters of an oil pumping plant and the damage ratio values as proposed by [4]

Damage state (Ds_i)		Damage Description	θ	β	DR_i
Ds_1	Slight/minor	Defined by light damage to building	0.12	0.60	0.08
Ds_2	Moderate	Defined by considerable damage to mechanical and electrical equipment, or considerable damage to building	0.24	0.60	0.40
Ds_3	Extensive	Defined by the building being extensively damaged, or pumps badly damaged.	0.77	0.65	0.80
Ds_4	Complete	Defined by the building being in complete damage state	1.50	0.80	1.00

Following the above parameters (Table 1), the risk function is derived by an integration of the annual rate of exceedance curve with the fragility curve, the damage ration (DR_c), and the replacement value (RV_c). The risk curve analysis shows that low-moderate ground accelerations, where the exceeded PGA is lesser than 0.8, have a major contribution to the total annual risk of the pumping station (Figure 3).

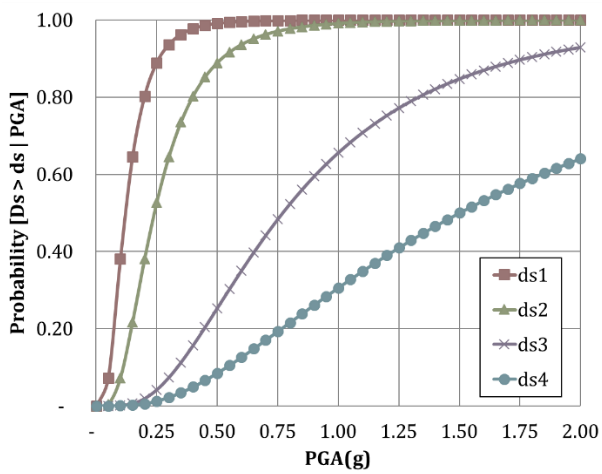

Figure 2 - Fragility curve for pumping plant

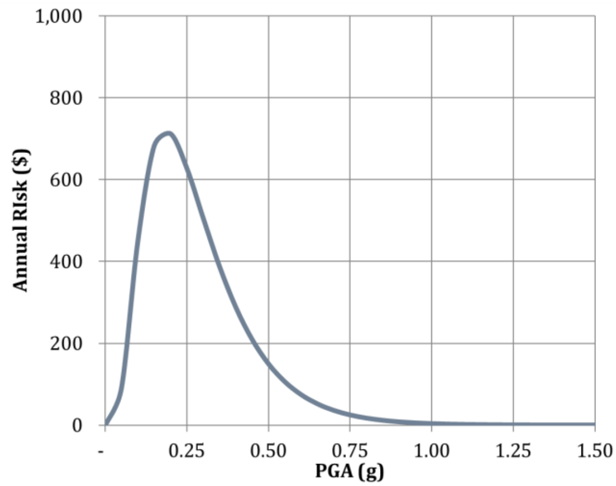

Figure 3 - Risk curve for pumping plant

One of the possible methods to reduce the potential damage of the PP in case of seismic event is anchoring the subcomponents of the station. This strategy is increasing the resistance of the subcomponents to overcome moderate level ground accelerations and subsequently increases the robustness of the pumping plant for seismic events. Implementation of this strategy modifies the fragility curve parameters for ds_1 and ds_2, which gives a relatively high probability to exceed this damage states in case of moderate ground for the unanchored plant while anchoring the subcomponents reduces the probabilities to exceed ds_1, ds_2 in case of moderate ground aFUlccelerations (Figure 4). This mitigation strategy reduces the total risk of the pumping plant. The reduction is mainly effect the damage that expected as a result of moderate ground motion. An analysis of the derived risk curves for unanchored and anchored plants shows that anchoring the components can reduce the risk by about 27% (Figure 5).

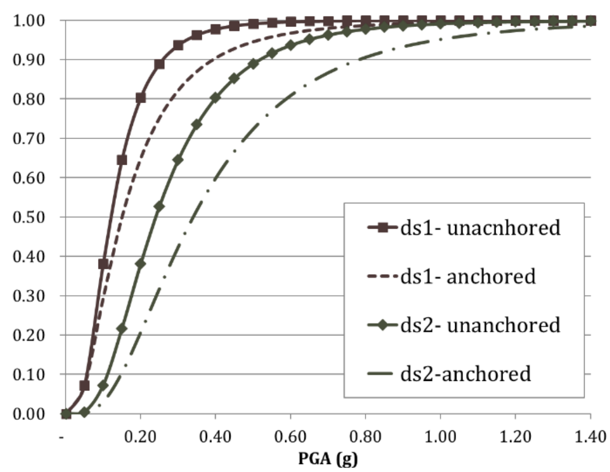

Figure 4 - Comparison of ds_1 and ds_2 for anchored and unanchored pumping plant

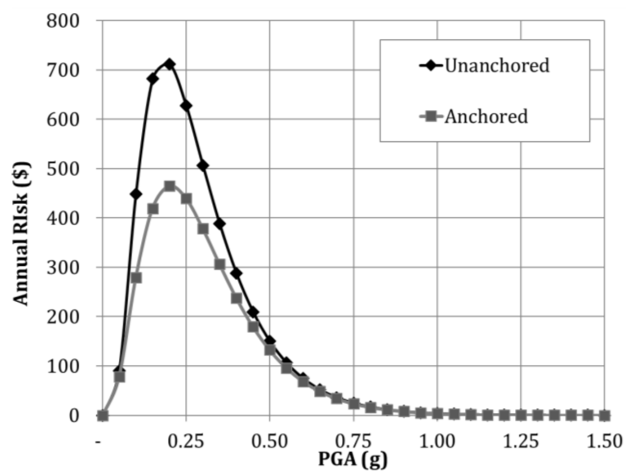

Figure 5 - Comparison of the derived risk curve for anchored and unanchored pumping plant

4. Seismic vulnerability function: Case study 2

This chapter demonstrates the derivation of a fragility function for exclusive critical infrastructures facility through a case study of an oil tank farm. In case of an exclusive facility or component of a system, it is desired to derive and use the best fit fragility curve. The main purpose of this step is to produce a unique fragility based on an aggregation of the fragilities of the sub-components (Figure 6). In this example, it is considered that the oil tank farm is composed of five main sub-components: building, storage tanks, power grid, backup generator, and mechanical equipment.

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4.1 Building

The control center of the farm is in a low-rise building. The building serves for the control and the supervision on the ongoing operation of the farm. In our case, the building is a one-story RC building. The fragility parameters are based on [6].

4.2 Tanks

Oil storage tanks are used for storage of different petroleum products for a long or a brief time; the oil farm consist several storage tanks that. The modern oil storage tanks are varying from 12-76m in diameter with heights to diameter ratio (H/D) is mostly lesser than one. The most common design type of tanks is cylindrical ground-supported tank due to their efficient resistance to hydrostatic pressure and can be easily constructed. In addition, most of the oil storage facilities are composed of welded steel with floating roof. Several fragility parameter sets are offered by the literature based on empirical data. The HAZUS procedure provides data for steel tanks categorized the tank only whether it is anchored or unanchored. In addition, [6], [10] suggest considering parameters such as H/D ratio and fill level. In this case, the fragility parameters are based on the values proposed for tank with H/D ratio lesser than 0.7, which are the most compatible for the tanks on the oil farm. Moreover, in case of tank farm, the fragility of the farm will be yield corresponding to damage states definition, and as a binomial distribution of k damaged tank of n total tanks in the farm.

4.3 Diesel generator

The diesel generator is used as emergency power-supply in cases the external power grid is fails. The generator is mostly varying by capacity, vibration isolation, and anchoring. In this case, the backup generator is a diesel generator with a Capacity of 350 to 750 kVA with unanchored equipment and without vibration isolation. The fragility parameters are based on [4], [20]

4.4 Power grid

The operation of the site is based on the ongoing supply of electric power. In our case, the electric power supply is based on two sources: In routine, the electric power supply to the facility is based on the local electricity distribution networks. in case, of a malfunction or damage to the external electrical path, a generator is placed in the facility to provide a solution until the electricity supply is restored. For this case study, the fragility parameters of the power grid are based on HAZUS methodology [4].

4.5 Mechanical equipment

For this case study, the fragility parameters for the mechanical equipment are based on HAZUS methodology [4].

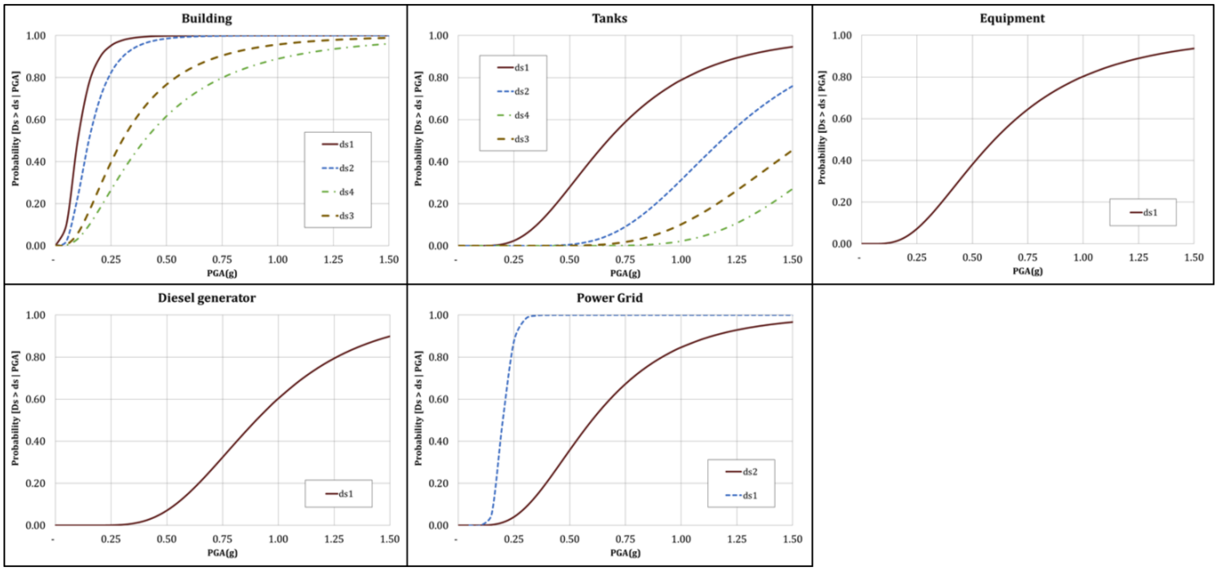

Figure 6 – Fragility curves of the system's sub-components

4.6 Development of the system fragility curve

Based on the fragility parameters of the sub-components and the system damage state definition one can develop a unique fragility curve for a specific system, which in our case, an oil tank farm. The composed fragility curve is composed of several curves that express the sequential damage states of the system. At the last step of the fragility development is the evaluation of the fragility parameters of each damage state (θ_{ds} and β_{ds}). This procedure can be implemented by Excel solver for each damage state. Figure 7 below presents the fragility curves of the oil tank farm based on those parameters.

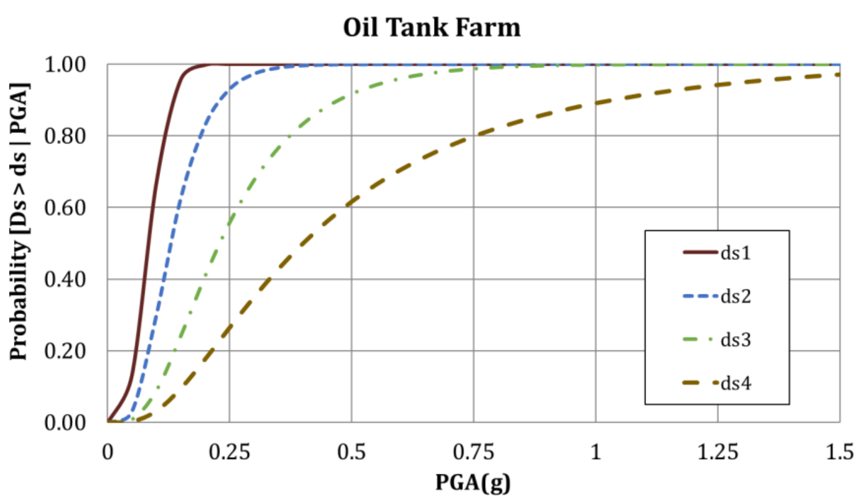

Figure 7 - Fragility curve of the oil farm

4.7 Comparison with the literature

A comparison of our results with fragility parameters that are proposed by [4] are presented in Table 2. The differences between the parameters are most likely due to the differences in the definition of the events that attributed to each damage state. It is required to perform further analysis to examine the sensitivity of the scenarios that are defined to each damage state and to associate the scenarios with the changes in the fragility curves.

Table 2 - Comparison of this paper results with fragility parameters that are proposed by (NIBS 2004)

Damage State	This research		NIBS 2004 [4]	
	θ	β	θ	β
Slight/minor	0.10	0.27	0.12	0.55
Moderate	0.15	0.52	0.23	0.55
Extensive	0.30	0.64	0.41	0.55
Complete	0.40	0.74	0.68	0.55

5. Sensitivity Analysis

The proposed methodology is coping with several uncertain parameters that are essential for the risk appraisal. The uncertainty of the seismic event is expressed in annual rate of exceedance, and the uncertainty of the damage because of the event is expressed in the fragility curve. The construction of fragility curve process aggregates the parameters of several fragility functions which are mainly based on prior studies. For some sub-components, several sources offer different fragility parameters for the sub-component. In those cases, relying on one of the sources will, in some way, effect on the risk curve. Therefore, it is very important to examine the influence range and the sensitivity of the uncertain parameters. In this sensitivity analysis, we examined the marginal cost of the sub-component median.

The following tables presents examination of a change of the median for each damage state of each sub-component ($\Delta\theta_{\mathrm{ds}_{sub-component}}$) and the following change on the medians of the tank farm damage states ($\Delta\theta_{\mathrm{ds}_{oil\ farm}}$) by value, the value in brackets expresses the percentage change. The first row presents the original values followed by three levels of changes in the median parameter: 50% reduction, 50% increase, and 100% increase.

Table 3 – Summary of the sensitivity analysis by sub-component. The value in brackets expresses the percentage change.

	Sub-component		Oil Tank Farm			
			0.082 (0%)	**0.128 (0%)**	**0.228 (0%)**	**0.4 (0%)**
	Ds_i	Ds_i^*	Ds_1	Ds_2	Ds_3	Ds_4
Building	$Ds_1 = 0.1$	0.05 (-50%)	0.049 (-40%)	0.128 (0%)	0.296 (30%)	0.4 (0%)
		0.15 (50%)	0.1 (22%)	0.128 (0%)	0.296 (30%)	0.4 (0%)
		0.2 (100%)	0.107 (30%)	0.128 (0%)	0.296 (30%)	0.4 (0%)
	$Ds_2 = 0.15$	0.075 (-50%)	0.061 (-26%)	0.073 (-43%)	0.228 (0%)	0.4 (0%)
		0.225 (50%)	0.088 (7%)	0.162 (27%)	0.228 (0%)	0.4 (0%)
		0.3 (100%)	0.089 (9%)	0.183 (43%)	0.228 (0%)	0.4 (0%)
	$Ds_3 = 0.3$	0.15 (-50%)	0.074 (-10%)	0.103 (-20%)	0.138 (-39%)	0.4 (0%)
		0.45 (50%)	0.083 (1%)	0.135 (5%)	0.282 (24%)	0.4 (0%)
		0.6 (100%)	0.083 (1%)	0.137 (7%)	0.315 (38%)	0.4 (0%)
	$Ds_4 = 0.4$	0.2 (-50%)	0.077 (-6%)	0.111 (-13%)	0.159 (-30%)	0.2 (-50%)
		0.6 (50%)	0.082 (0%)	0.132 (3%)	0.259 (14%)	0.596 (49%)
		0.8 (100%)	0.082 (0%)	0.133 (4%)	0.274 (20%)	0.777 (94%)
Tanks	Ds_1 =0.67	0.335 (-50%)	0.081 (-1%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		1.01 (50%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		1.34 (100%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
	Ds_2 =1.18	0.59 (-50%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		1.77 (50%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		2.36 (100%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
	Ds_3 =1.56	0.78 (-50%)	0.082 (0%)	0.128 (0%)	0.227 (0%)	0.4 (0%)

		2.34 (50%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		3.12 (100%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
	Ds_4 =1.79	0.9 (-50%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.389 (-3%)
		2.685 (50%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		3.58 (100%)	0.082 (0%)	0.133 (4%)	0.274 (20%)	0.777 (94%)
Generat	Ds_1 = 0.9	0.45 (-50%)	0.082 (0%)	0.128 (0%)	0.218 (-4%)	0.4 (0%)
		1.35 (50%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		1.8 (100%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
Power grid	Ds_1 =0.15	0.075 (-50%)	0.064 (-22%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		0.225 (50%)	0.083 (1%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		0.3 (100%)	0.083 (1%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
	Ds_2 =0.6	0.3 (-50%)	0.081 (-1%)	0.125 (-2%)	0.228 (0%)	0.4 (0%)
		0.9 (50%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
		1.2 (100%)	0.082 (0%)	0.128 (0%)	0.228 (0%)	0.4 (0%)
Equipm	Ds_1 =0.60	0.3 (-50%)	0.081 (-1%)	0.123 (-4%)	0.228 (0%)	0.4 (0%)
		0.9 (50%)	0.082 (0%)	0.129 (1%)	0.228 (0%)	0.4 (0%)
		1.2 (100%)	0.082 (0%)	0.129 (1%)	0.228 (0%)	0.4 (0%)

From this examination, we can see that the most significant sub-component in most cases is the building; the fragility curve parameters of the entire system are most sensitive to inaccuracy in the fragility parameters of the building. However, in most cases the change in the farm medians is much smaller than the change in the sub-components median. Moreover, because of the complexity of the system, an inaccuracy of a single parameter will not significantly effect on the risk evaluation of the entire system.

6. Conclusion

This paper presents a probabilistic risk appraisal methodology which intended to be used as a decision support tool for decision makers in order to set the priority of mitigation strategies based on the seismic risk expectancy of critical infrastructures.

This paper presents an implementation of this methodology through two case studies: oil tank farm and a pumping plant. The pumping plant case demonstrates the development of a seismic risk function. In this case, the risk expectancy curve reveals that most of the risk is concentrated at the low-moderate peak ground accelerations levels. A possible mitigation strategy was examined, and the subsequent reduction of risk was analysed. It was found that attending the mitigation strategy to the most critical range of ground accelerations can reduce the overall risk expectancy by over 25%. In addition, this paper focuses on the development of an exclusive fragility curve for a unique system, for those cases that the generic fragility curves that are available in the literature are insufficient. The implantation of this approach is presented through the oil tank farm case study; in this illustration, the oil tank farm is composed of five main sub-components: building, storage tanks, power grid, backup generator, and mechanical equipment. Subsequently, based on the fragility parameters of the sub-components and the system damage state definition the fragility curve of the system was yield. A comparison of the results with fragility parameters that are proposed in the literature reveals that the differences between the parameters are most likely due to the differences in the definition of the events that attributed to each damage state. In addition, a preliminary sensitivity analysis of the uncertain parameters (median of the damage states of the various sub- components) was performed; it was found that due to the complexity of the system, an inaccuracy of a single parameter, in most cases, will have insignificant effect on the total risk expectancy of the entire system.

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Research on Regional Characteristics and Clustering Protection of Shanxi Historical Villages and Towns

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Abstract

Historical villages and towns are considered as cultural phenomena, of which the origin, generation, and development are closely related to historical environment in certain spatial areas. Historical villages and towns show adaptability to historical environment; moreover, historical villages and towns have also enriched various forms of regional history, presenting different characteristics. In this study, historical context of villages was analyzed by considering geographical environment, geopolitics, and defense policies of Shanxi province in China. Central land that supported frontier was identified; moreover, the exchange between silk and iron was encouraged. To compile regional pattern of "defense and circulation," special types of old villages were identified in Shanxi province, China. Military-castle-type structures are present along the Great Wall of China. Businessmen's-courtyards-type structures are present in Fenhe Basin; settlement clusters of castles are present in Qinhe Watershed; port-type settlements are present along Yellow River, and mountain-pass type towns and villages are present along Taihang Mountain. Geographic space, humanistic space, and administrative space were taken into consideration. This study takes a further step to claim "four areas and two lines" as spatial pattern of old villages in Shanxi province of China. Thus, a "clustering" protection framework was developed.

Keywords: Shanxi historical villages and towns; regional patterns; evolution mechanism; clustering protection ;

Shanxi province has an important position in China's defence deployment, rivers and mountains form a barrier to keep away outsiders in the ancient times. Especially in the Ming and Qing dynasties, the development of iron and silk business made Shanxi an early economic opening area in China. Ancient villages and towns have developed to a peak under this background of "Defence and Circulation" and formed a complete spatial system. The existing traditional villages include 36 military-castle-types villages along the Great Wall, 27 businessmen's-courtyards-types villages in the Fenhe River Basin, 31 settlements clusters of castles in Qinhe Watershed, and other characteristic clusters. These villages form ferry crossings along the Yellow River and gateways of Taihang Mountain， and carry the social memory of Shanxi in the Ming and Qing dynasties.

1. Regional model of ancient villages and towns in Shanxi

There are about 1258 ancient villages and towns with traditional features in Shanxi Province. The distribution within the province is spatially coupled with the geographical space. As a whole, it has the regularity of "concentrating along the edge of the basin" and forms the "four areas and two lines" rural heritage unit in Shanxi Province. Those ancient villages and towns has regional characteristics of high spatial concentration, strong cultural connection, and distinctive regional characteristics.

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1.1. the military-castle-types villages along the Great Wall: City-like structure, barracks organization

The military-castle-type villages in the north of Shanxi Province, including Guanpu, Tunpu, and Xiangbao, is the product of the military deployment under the country’s geopolitics. The distribution of these ancient villages and towns is located along inner and outer lines of the Great Wall, with Datong town and Shanxi town as the core, and barriers as the node. The stretched Great Wall, densely packed abutments, thick walls, and gateways and passages scattered inside and outside the Great Wall preserve the historical environment of the Ming and Qing dynasties. The current appearance is completely the result of natural weathering. After the defensive function disappeared, the military system between such frontier settlements was deconstructed and each settlement was involved in the development of local urban and rural areas: some became cities such as Datong, some became counties such as Zuoyun and Youyu, and many of them became townships. Most of them are fixed in the villages. Overall, this difference in development path is similar to the administrative level of “Du, Si, Wei, and Suo” and the defence level of “Zhen, Lu, Bao, and Zhai”. The history of the ancient villages and towns is mostly at the level of “Wei” and “Suo” and exists in the form of “Bao”. The military-castle-types villages along the Great Wall is located within the country's overall defence system, as an ideal military strategy deployment, it has unified construction regulations from top to bottom, manifesting itself as a basic model of “City-like structure, barracks organization”.

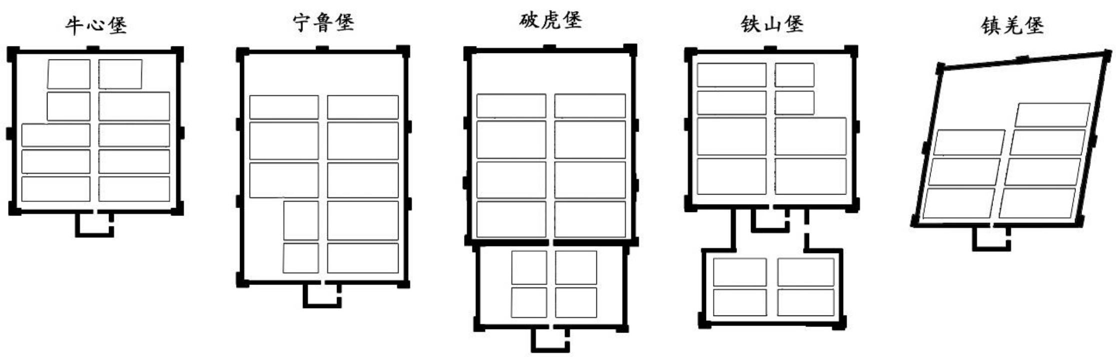

Fig.1. City-like structures of military-castle-type villages in the north of Shanxi Province

1.2. The businessmen's-courtyards-types: Castle-courtyard Structure, Lifang Style

The businessmen's courtyard in Centre of Shanxi Province is called Jiabao and is mainly concentrated in the Fenhe river basin of the Taiyuan Basin. The development of Jiabao relied on the developed agricultural economy of the Taiyuan basin and the traffic hubs connecting the north and the south. It developed in the social environment of the border trade in the early Qing Dynasty. Shanxi ticket traders who have made their fortune in the international trade of tea have built a large number of family-owned courtyards in Taigu, Jixian, Pingyao and Jiexiu. These courtyard`s bases are connected in layers. They are spread around Middle Street. The latitude and longitude are clearly arranged in an orderly manner, forming a castle-style family courtyard, such as the Hongmen eight-castles at Wangs of Jingsheng Village in Lingshi County, old and new three-castles at House of Jia Village in Jiexiu City, Hexun six-castles at Duan Village in Pinyao County, the basic mode is castle-courtyard structure, lifang style.

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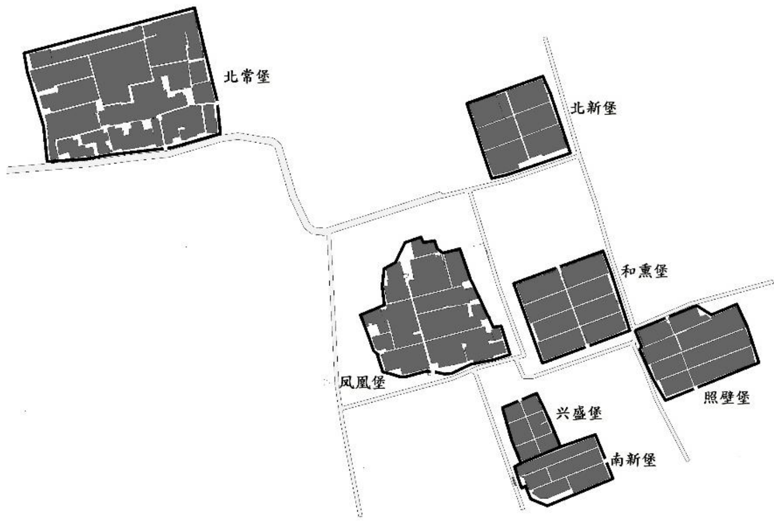

Fig.2. “One Village Six Castle” Castle-courtyard Structure at Duan Village in Pinyao County

1.3. Commercial towns of Qinghua ancient road: Channel Structure, Town Style

The land resources in southeastern Shanxi are poor, but rich products, especially coal and iron resources provide the material basis for the development of commerce and trade, which has spawned the rise of Zelu merchants. During the Ming and Qing dynasties, with the prosperity of the commodity economy in the Zelu region, the flow of goods and materials in the region developed. As a result, a number of well-regulated commercial towns have emerged on the convenient traffic lanes, known as the town economy. Qinghua Avenue promotes the development of horse caravan and camelback team. “...the west of the Qinghua Grain transporter is like a water line. In Taihang Mountains, people stayed up all night. The bazaar of the small town (Run City) was very prosperous. Every day, two or three thousand animals were sent for sale. There are more than 30 douhangs, each of whom has more than a dozen fellows.” These commercial towns, unlike farming settlements, are the result of a flourishing development after the intervention of the regional traffic. These villages and towns have a loud street name, whose status is much higher than that of the villages and towns, such as Hangshan Town – Zhoucun Town, Sanli Long Street - Shangfu Village, Wuli Long Street - Guobi Village, Sanmen Ancient Street - Runcheng Town, etc. channel structure and town style is the basic model.

Fig.3. Channel Structure at Shangfu Village in Yangcheng County

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1.4. Settlements in the Southern Shanxi Basin: Clan Structure, Ruin Landscape

Southern Shanxi is located in the golden triangle of the Yellow River at the junction of the Shanxi, Shaanxi and Henan provinces. It is located east of the Yellow River and is known as “Hedong”. It is the birthplace of the Chinese civilization, and the farming community is in the legend of Nuwa, Tianshui, and Yugong. The southern part of Shanxi Province has been the centre of politics, economy and culture since Xia Dynasty, Shang Dynasty and Zhou Dynasty. The thickness of cultural accumulation is generally 1-2 meters. The ancient villages and towns are in the layered layer of ancient civilizations. Therefore, ancient villages and villages in southern Shanxi under the influence of the ancient Hedong culture, the ancient villages and towns are intertwined with ancient ruins, and through the millennium, they have the dual characteristics of “clan structure and ruin landscape”.

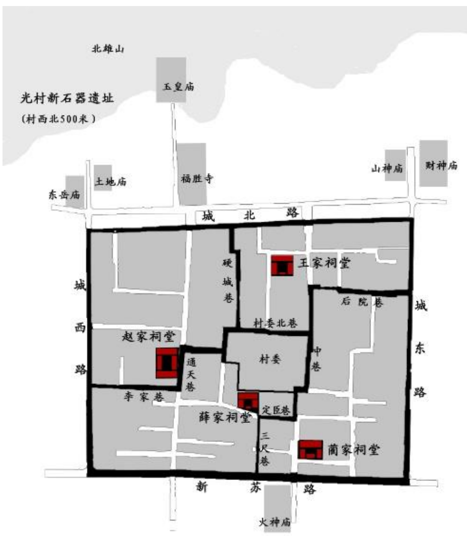

Fig.4. Clan Structure at Shangfu Village in Yangcheng County

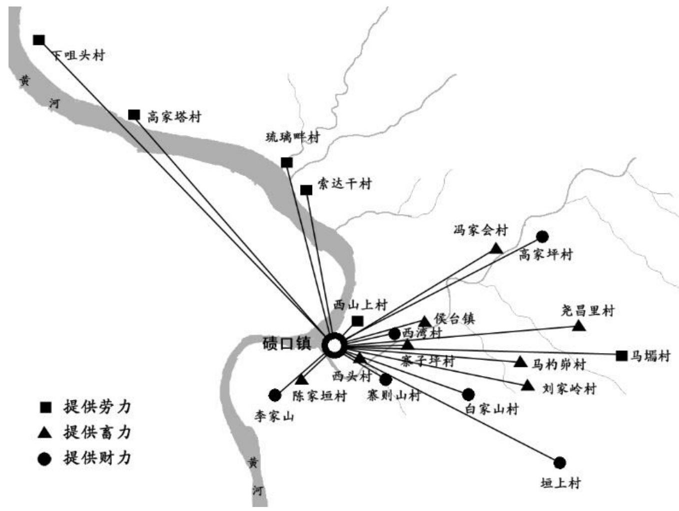

Fig.5. group structure of Qikou town and the surrounding villages

1.5. Ferry Villages on the banks of the Yellow River: Group Structure, Stacked Yard Formation

In western Shanxi, Yellow River is used as natural barriers, and Yellow River is also used as traffic channels. There are numerous ferry crossings along the Yellow River coast. Among them, Maojindu, Fenglingdu and Dadudu are called the ancient three major rivers of the Yellow River. “Ferry Village” is a water and land transportation hub formed by ferries. During years of Qianlong in Qing Dynasty, The grain and oil transport corridor from Shanxi to Mongolia was opened, and some ports at the traffic nodes were able to develop into bustling port commercial towns, driving the development of the surrounding villages. According to the records of Linxian County in the Sixth Year of the Republic of China, “In the ancient times, Qikou was a place of namelessness. During the Qing dynasty, the rivers and rivers overflowed, the Houtai Town in the Southern District of the county was destroyed, and the Qufu Township on the east bank of the Yellow River. The merchants of the two towns gradually moved to Qikou. In the early years of Daoguang, the business of Qikou developed and became a land and water transportation port. The ferry villages on the bank of the Yellow River cascade up from the mountains and develop in harmony with the surrounding rural areas, The basic model is “ Group Structure, Stacked Yard Formation ”.

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1.6. Guancun of Taihang Eight Trails: Gateway-City Structure, Precipitous Scenery

Taihang Mountain in the east of Shanxi separates Shanxi and Hebei provinces. It is difficult to climb over each other. The ancients explored a mountain road that could be opened to traffic and became the only way for Shanxi, Hebei, and Henan provinces to cross the Taihang Mountains, which is called Taihang Eight Trails. Because of the existence of mountain trails, there are passages for exchanges and trade between the hinterland of Taihang Mountains. The military builds a large number of gates at the throat of the trails to guard country, such as the famous Niangziguan, Dongyangguan, Hongtiguan and Tianjingguan. "Everyone must pass the gate and never open it". In addition to the garrison defensive, gateways also have official functions such as letter transmission, traveller inspection and customs duties, etc. It has fixed houses and staffs, needs a corresponding supply system. Therefore, gateways are the node in the Taihang Mountains. A series of “Guancun” appeared in the ancient road, and its basic model was “Gateways-City Structure and Keeping It Secure” (Fig. 6).

Fig.6 Gateway-City structure of Zezhou city Tianjingguan Village

2. Characteristic features of ancient villages and towns in Shanxi

In Fei Xiaotong's “local China”, there are two types of society in China: one is the village where the peasants live, and the other is the controlled by the empire's government. "On the one hand, it is a top-down imperial power, and on the other hand, it is the bottom-up squire power and clan power. These two societies operate in parallel and interact with each other, form a rural governance model that emperor didn't act but the country achieved governance. The unique and uniquely 'two-track politics' model that describes the logic of traditional Chinese politics is established.”[3]

2.1. Nine borders System and Defence Situation

Shanxi is a unique province in the country’s geopolitics. It is located west of the Taihang Mountains and east of the Yellow River, and is named “Shanxi” and “Hedong”. The mountains and rivers forms a natural defense barrier for the military. Gu Xiaoyun said: “The world must be taken from Shanxi.” With an average altitude of about 1,000 meters, Shanxi poses a condescending trend to neighboring provinces and regions. In the cultural axis of Central Plains in China for more than 2,000 years, Shanxi has been the main battlefield for the collision and integration of agricultural culture and nomadic peoples. It is a defensive center of the Central Plains regime at the northern border. Especially in the Ming Dynasty, the military situation in Ming and Meng escalated to form a confrontational military situation. The

Ming government turned from a strategic offense to an active defense, abolished the state administration of the Yuan Dynasty in the border zone, and established a military-government ruling agency — Du, Si, Wei, Suo, and established the strategic thinking of founding nine borders to defend the country.

2.2. Kaizhong System and Circulation Pattern

“Kaizhong” is a system of investment promotion that was created by the rulers of the Ming Dynasty for military purposes [2]. Under the nine borders defense system, a huge consumer market has emerged in northern Shanxi. In order to ensure the frontier supply, the Ming government uses its salt monopoly privilege to attract traders to provide food for the frontier, and it becomes a major way for merchants to gain profits. For ancient villages and towns, the influence of “Kaizhong” system is comprehensive and profound. It has extensively changed the form of villages and towns, has transformed the farming society into a commercial society. On the one hand, relying on local resources and traffic conditions, a large number of commercial towns and customs markets have emerged. On the other hand, many families have become wealthy businessmen through wealth accumulation, which has spawned a large number of Shanxi businessmen's courtyard.

3. Clustered protection measures for ancient villages in Shanxi

Ancient villages and towns in Shanxi Province as a "rural environment that can witness a certain civilization, a meaningful development, or a certain historical event" is not a simple sum of settlements, but a series of overall relationships expressed through history, landforms, and regional societies. Therefore, starting from the special status of Shanxi Province in the historical process of China, ancient villages and towns are regarded as the carrier of social memory and the materialized form of social memory, characteristics are identified in the formation motivation and historical evolution, and protection is achieved in an overall manner. Here, the concept of “clusters of ancient villages and towns” proposed in this paper will historically be called “clusters of ancient villages and towns” that are culturally related, similar in characteristics, and geographically similar due to some common mechanism.

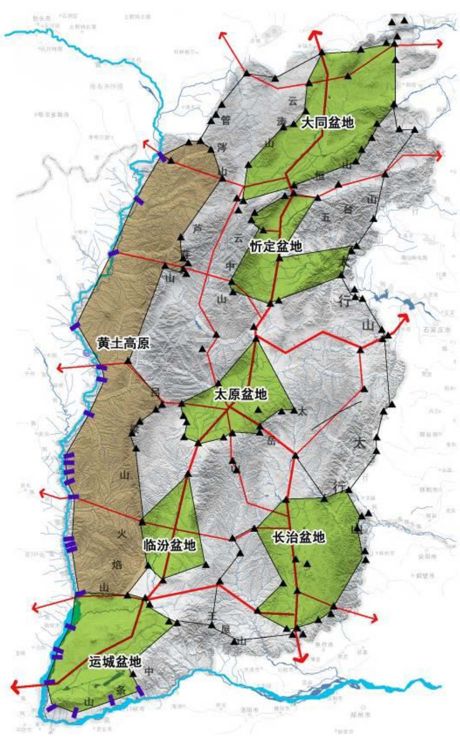

Fig.7. Shanxi Gateway - Basin distribution map

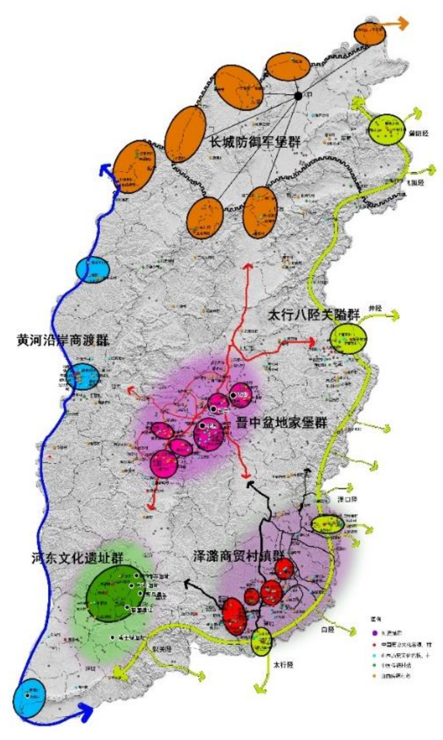

Fig.8. map of Shanxi ancient village and town cluster protection system

First of all, the construction of ancient villages and towns clusters includes several levels, in a cluster system of regional space, there should be multiple clusters. Based on the natural geographical environment and regional social background, ancient villages and towns of Shanxi formed six cluster systems， including the military-castle-type along the Great Wall, businessmen's-courtyards-type in Fenhe Basin, settlements clusters of castles in Qinhe Watershed, port-type settlements along Yellow River and mountain-pass type towns and villages along Taihang Mountain. They are further divided into 25 clusters based on local terrain units and administrative affiliations (Fig. 8).

Secondly, the cultural connotations of ancient villages and towns clusters come from different external actions. They are assembled under external intervention to form a cluster structure. The greater the force, the stronger the correlation between villages, and the more prominent the type characteristics. Such as the Yellow River bank commercial wharves clusters, with Qikou as the center. Labor resources, financial resources, and storage power around this commercial town, make the surrounding villages clustered into an interconnected whole, the involvement of flood and drought wharves is the dynamic mechanism of cluster formation.

The purpose of constructing clusters is to reorganize the ancient villages and towns that have their own politics as a whole, thus form a complete historical commentary system, and participate in the development of regional urbanization and cultural tourism in a collaborative manner.

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Review of collusion and bid rigging detection methods in the construction industry

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Abstract

Collusion and bid rigging are deplorable practices, forbidden by law. They are harmful to the society and dangerous for a free market economy. Due to the high value of construction industry production and the importance of the time factor, anti-competitive behaviour in that sector can result in losses extremely significant for the national economy. Effective elimination of cartels and bid rigging requires detection, prosecution and successful penalization of cartels. Disrupting already existing cartels and deterring new ones from emerging is efficient only when there is an effective cooperation between the three above mentioned stages. Classification and brief description of numerous existing collusion and bid rigging methods were performed in this paper. As a conclusion, the author presents an idea to combine AI (Artificial Intelligence) and BIM (Building Information Modeling) together as useful tools for early detection of collusion and bid rigging in public tenders.

Keywords: artificial intelligence, artificial neural networks, bid rigging, BIM, collusion, fuzzy logic

1. Main text

Bid rigging and other anti-competitive agreements are not easily observed by other market participants. Moreover, building entrepreneurs are usually aware that such practices are illegal and it is necessary for them to remain undetected. This is the reason for why the fight against anti-competitive agreements led by public services requires particular measures, especially swift exposure and effective evidence collection [1]. Hiding evidence of economic activity or refusing to cooperate with competition authorities occurs also in other types of investigation. However, only in case of anti-competitive agreements, such actions constitute a fundamental obstacle to overcome which may affect the efficiency of public services. Even the most experienced and well-equipped public services are not characterised by high efficiency of cartel detection. Measuring the efficiency of cartel detection is as difficult as detection itself; irrespective of the implemented method, economist estimate the upper limit of efficiency index for 10-20 % [2]. In order to improve detection statistics, the research on enhancing the effectiveness of anti-competitive agreement detection tools and creating new ones is being conducted nowadays. They can be efficient if they are an integral part of the entire cartel detection system, consisting of such elements as violation detection, promotion of competition, tools of active evidence collection (e.g. search warrants or wiretapping) and the policy of preventive punishment. In the recent years, rapid IT development took place, which enabled the collection, storage and processing of huge amounts of data also in the construction industry. On the other hand, previously inconceivable manners of anti-competitive agreements arose simultaneously [3]. Enormous databases provide the possibility to observe technico-

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economic phenomena. However, considering these large amounts of data, its exploration with the previously used tools became problematic. In such cases, artificial intelligence techniques such as neural networks or fuzzy modelling, proved to be useful. Implementing artificial intelligence into construction industry might allow for detection of abnormalities, classification of phenomena (i.a. anti-competitive agreements) [4,5] or prediction of delays [6,7]. In this paper, the author provided an overview of the existing methods of anti-competitive agreement detection. An innovative idea concerning bid rigging detection in the construction industry is presented in this paper; it may utilize an electronic procurement platform, BIM and artificial intelligence methods (neural networks, fuzzy modelling and data mining).

2. Methods of anti-competitive agreement detection

2.1. Econometric and statistical methods

Econometric methods were implemented by Porter and Zona [8] in order to analyse the market for milk sold to schools in the State of Ohio, USA [8]. They performed various tests which enabled them to assess what factors influence the decision whether to submit a tender and at what price. Considering that the analysis was being undertaken already after the detection of an anti-competitive agreement, behaviour of each tenderer was being compared to the reference group, comprised of entrepreneurs not participating in the collusion. The behaviour of collusion participants varied significantly from the behaviour observed in the reference group. The greater likelihood to submit an offer for tenders launched by the most closely located recipients was one of the relevant discriminants among relevant indicators of their behaviour (which is consistent with the market partitioning mechanism). The cartelists submitted offers for tenders, during which also other cartelists were present, more often than it would logically follow from the competitive business model (consistent with the fake tender offer mechanism). What is interesting, the values of offers submitted by the collusion members varied accordingly to the consignees' location. The closer the location, the higher was the offer. Such practices are inconsistent with the competitive model, according to which transportation costs should cause an increase of offered prices proportionately to the increase of distance.

The same authors performed an ex post examination using another method to analyse the changes in behaviour of a certain cartel. It operated in the 1980s, on the public road construction market in Long Island, New York [9]. Almost always more than just one collusion member participated in rigged tenders. Evidence shows that the fake tender offer mechanism was being exploited. The authors examined whether there are statistically relevant connections between offers from the cartelists' group and the reference group. A simple test showed, that the „rigged" offers were less dispersed that the competitive offers (smaller difference between the two lowest priced offers). The estimates of the probability of submitting a winning offer in case of each company in respective tenders allowed for the application of a test for the distribution of the offers' order. The actual distribution of offers was consistent with the theoretical one (resulting from the estimated pattern) for the group of non-cartelists. The cartelists' behaviour significantly differed from the behavioural model. Their offers were less strictly connected with the measures of service costs than the offers of entrepreneurs not participating in the collusion. Other examples of research on bid rigging detection in the road construction industry are the works of Gabrielli [10], Podkolzina [11] and Padhi [12].

Bajari and Ye created a method of testing the behaviour of the collusion members with regard to the autonomy of submitted offers [13]. It was proved that bid functions must meet two conditions in the competitive balance: conditional independence and exchangeability. The first condition requires that offers of independent entrepreneurs should not be correlated with each other after the analysis of all individually observed cost factors. Exchangeability means that the generic offer distribution remains the same after entrepreneurs have exchanged individual cost factors. Even if there are colluding parties in a given tender, the condition of conditional independence and exchangeability will be satisfied by the participants not involved in the collusion. Thus, the Bajari and Ye's method may allow for factual identification of the cartel members as opposed to the test of Porter and Zona which is difficult to apply without the preceding hypothesis on the cartel's composition.

Marshall and Marx examined the operational schemes of a cartel and defined a super-plus factor of a cartel's existence [14]: "A reliable, econometric prediction model which takes into account the influence of all external factors relevant for the price, estimated from comparative data concerning non-coordinated behaviour and predicts the prices inconsistent with a factual price path during the time or at the place of collusions, on an assumed level of confidence". Such a model is being used more often for the estimation of overcharge in cases of private lawsuits [15]. In terms of cartel detection, the goal is not to calculate the overcharge paid by contractors, but to check whether the prices were being overstated. Descriptions of such model types can be found in the Oxera report [16] for the European Commission and in the following document of the Commission [17]. The key to efficiency is to establish an appropriate benchmark (most likely the period of time free of any collusion), to construct a model and to prepare any data allowing for the consideration of all relevant factors influencing the price formation in the competitive balance.

The analysis ordered by the British Office of Fair Trading [18] and performed by Grout and Sonderegger is a known example of an econometric method's application in detection of anti-competitive agreements. It was a screening test of 181 industrial sectors. The authors of this study estimated the level of influence of sectors' structural features (size of the market and its growth rate, cost of labour force, R&D expenses, concentration rates C3 and measures of the equity barriers for market entry) on cartel incidence in the given sectors. Due to the fact that cartel incidence is an unobservable variable, another one served as a response variable: the detection (or no detection) of a cartel in a given sector by the European Commission or in the United States in the years 1990-2004. The results of the logit model estimation were further used for the calculation of the probability of cartel occurrence in those sectors, where cartels had not been detected under the previously mentioned jurisdiction. Grout and Sonderegger's method can be summarized as identifying sectors similar (in terms of structural features) to those, in which cartels had been previously detected.

Authors of the report on corruption prepared for the European Commission used a comparable approach [19]. The report concerns the detection of abnormalities in public tenders, with horizontal bid riggings as the main group of abnormalities (48 % of analysed cases). The detection (or no detection) of abnormalities in a given tender constitutes a response variable. However, the authors highlighted that this particular variable is a good measure of factual occurrence of abnormalities, for the sample of tenders put under regression analysis was scrutinised in this regard. The estimation of a probit model was used by the authors to identify which of the chosen explanatory variables (e.g. the shortening of tender procedures, offerents' complaints/appeals, exceeding the estimated budget, unreliable filling of announcement forms, changes to the subject of a tender, tender values) are statistically relevant for the probability of abnormality occurrence. Statistically relevant variables were emphasised as red flags indicating possible abnormalities. The incidence rates of such selected indicators were used in the subsequent action to assess the risk of abnormalities occurrence, with a distinction into sectors and member countries.

2.2. Indexing methods

Harrington was also running research on the methods of cartel detection and bid rigging [20–23]. He established the set of indicators (regarding price behaviour and market shares) used for detecting cartels in screening tests. These indicators are connected to a structural gap in the prices and they may point towards the creation or dissolution of cartels [22]: increase of prices, accompanied by their unification; the period of permanent price increase, preceded by their sudden drop; increase of prices with a concurrent decrease of import rates; a strong correlation of prices between competitors; a great uniformity of prices and other parameters of a product or services; low price differentiation; less fluent price fluctuation; prices undergoing systematic changes; stability of the companies' market shares over time; negative correlation of a company's shares in the market (stock buybacks instead of trade wars).

Marshall and Max identified a slightly different set of indicators, dividing them into plus factors and super plus factors [14]. Some of them, especially super-plus factors, are quite complicated or require hardly available data, hence are not suitable for screenings. Although indexing methods do not require econometric modelling or statistical testing by the rule, they may employ certain statistical measures. However, such an approach does not disqualify formal statistical testing. The work of Bejger is an example of statistical inference used for detection of anti-competitive agreements. He applies statistical testing to i.a. assessment of the stability of the market shares belonging to the members of a cement cartel which existed in the years 1998-2006 in Poland [24].

Individual factors do not always guarantee low levels of type II errors. This is the reason for why screening programmes use multivariate methods of analysis more often [15]. The markets are being examined with regard to the occurrence of several indicators of anti-competitive collusions. In case of extensive research, e.g. Bid-Rigging Automated Analysis System created by The Korea Fair Trade Commission [25], such methods allow to rate tenders or bidders, as well as to create rankings of the risk of abuse, which increases the efficacy of successive actions of antitrust authorities. Another example of a multivariate method of analysis is Competition Index created by The Netherlands Competition Authority. It utilises 9 structural indexes (e.g. high level of market concentration, slow dynamics of demand, high level of participation in trade associations), which may facilitate the process of creation and existence of a cartel [26].

The weighting of indicators allows for creating an index which organises industry sectors according to the level of occurrence of anti-competitive agreements. It is worth mentioning that the methodology of index construction (especially weighting procedure is not entirely arbitrary, but it was verified through the comparison of indexing results with independent measures of competition in the industry sector (i.a. with an increase rate of the sector's productivity). A similar index (Aggregated Index of Competitive Pressure) has been established by the economists from the Romanian Competition Council [15].

Indexing methods originate from economic theories of oligopolistic coordination or are based on data regarding the activities of previously detected cartels. The expression of 'data mining' refers to a broad collection of the methods of irregularity detection or to the patterns in big data sets without an a priori assumption that there are existing theoretical or empirical basis for the occurrence of particular patterns. Data mining methods has been long applied for the detection of fraud and abuse in companies and they may be potentially used also for anti-competitive agreement detection, bid rigging in particular. As opposed to the indexing methods, such examination involves analysing data for the purpose of detecting some correlation or reliance and verifying whether observed patterns of behaviours are consistent with any other (previously known or new) collusion mechanisms. Therefore, they might help to detect the irregularities irrespective of information on the collusion members' identity or the mechanism of their cooperation. Data mining techniques may be complementary to the indexing methods or even serve as the foundation for the multivariate method creation. Such techniques are being used by i.a. the designers of the Bid Rigging Analysis System. Other techniques of fraud detection, such as tests for data manipulation, based on the Benford's law analysis, are also potentially fit for detection of anti-competitive agreements.

The usage of a multi-step algorithm may significantly improve the efficiency of anti-competitive agreement detection. Such an algorithm consists of running several consecutive tests, usually by the means of behavioural indicators, in order to successively narrow the groups of markets (tenders) or entrepreneurs suspected of the participation in a collusion [15]. A study carried out by Imhof et al. is an example of such an approach. They revealed the details of a procedure, which was performed during the tenders for construction contracts ordered by the Swiss cantonal authorities in 2004-2010 [27]. A five-step procedure was applied. In the first step, the number of dubious tenders was limited from 282 to 80, based on the contestatory index developed for the need of this study. Secondly, the number of examined companies was narrowed to the most active 17. Next, the entrepreneurs were split into groups, inside which they might have potentially cooperated, based on their mutual interactions during the biddings. In the fourth step, the group composition was verified with regard to the geographic scope of their activity. Lastly, behaviour of given pairs of entrepreneurs was analysed and then presented on the graphs in order to compare their normalised price offers in these tenders, in which both parties participated. The application of this algorithm allowed for specifying several regions, where the entrepreneurs' behaviour resembled the mechanism observed in the previously detected collusion for road construction contracts in the canton of Ticino.

3. Classification of anti-competitive agreement detection methods

The division into reactive and proactive techniques constitutes the basic classification of methods detecting horizontal collusions. Reactive techniques include mostly passive waiting for the evidence of collusion. Opposed to them, proactive techniques consist of active searching for such evidence. The fundamental advantage of reactive methods is their simplicity and low cost. Proactive methods often require greater amounts of workload and analytical skills. Some of them are dependent on the access to particular data. The fact that they do not provide direct evidence of an anti-competitive agreement, but rather allow for retrieving indirect evidence, is an additional flaw of proactive methods. The least popular are individual sources of information, infiltration and other operational methods, as well as screening tests and econometric studies [15,20].

All above mentioned methods have the same goal. What is more, every one of them restricts the resources of antitrust authorities to a certain level. That is why some of the fair trade offices may see such methods as substitutable. It may lead to the decrease of their variety and to the selective application of only those most cost-efficient. Leniency programmes have recently become the most preferable method [21,28–30]. Their beginnings extend to the 1970s, when the first leniency programme was implemented in the USA. Nowadays, such programmes are present in the majority of the countries respecting antitrust law, including all OECD members. The efficacy of leniency programmes made some of the countries use them as the main method of cartel detection. The programmes resulted in so many requests for leniency that some antitrust bodies find other methods unnecessary, especially the costly proactive methods. The lack of proactive techniques of anti-competitive agreement detection causes members of the cartels already detected, unstable or at their end to submit requests for leniency, as these cartels are the most prone to seeking settlement. Thus, the leniency programme becomes a measure to acquire evidence solely against cartels at the end of their existence, and the preventive function of the programme is greatly restricted. The lack of proactive performance of the authorities makes it impossible to break up the cartel otherwise than from the inside, and it is not an efficient

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way in terms of a cartel steady for its members. Proactive methods pose a risk of a cartel detection from the outside, which may prevent another cartels from emerging. However, they do not provide any evidence of collusion. Reactive methods destabilise the existing cartels and are a source of direct evidence of collusion. Therefore, proactive and reactive methods should be seen as complementary and it ought to be tried to determine their appropriate proportions, considering the characteristics of a discussed market, legal system and the analytical abilities of antitrust bodies [15]. Intuition and knowledge of the actual functioning of the market are greatly important in the detection of anti-competitive agreements.

3.1. Reactive methods

Notification is a basic passive method of cartel and collusion detection. The notices may come from contractors or customers, who often identify the dubious behaviour of entrepreneurs quite adequately. What is more, other offices of public service (the prosecution, regulatory bodies) as well as other antitrust authorities can also submit notices. Notices originating from whistleblowers, thus insiders – former or current employees of the companies participating in collusions – are particularly valuable, for they usually include direct evidence of collusion. Reward schemes (for paid informants) and leniency programmes are the two most serious and grave reactive methods. The cement collusion on the Polish market can be shown as an example of leniency program application [1,24].

3.2. Proactive methods

One of the simplest proactive techniques is the surveillance of publicly available data sources: the public media, the information supplied by economic intelligence or the news on interventions carried out by antitrust authorities in other jurisdictions. Another valuable source of intel on alleged problems in a given sector might be the analysis of complaints reported to an antitrust authority. A single report against an entrepreneur might not seem alarming but continuous complaints on the companies from the same sector might indicate the lack of effective competition, therefore also anti-competitive agreements. Market research may include retrieving and analysing data concerning a given sector. Although infiltration or other operational and economic methods seem efficient, they are being used quite rarely.

3.2.1. Statistical predicative analysis and indexing methods

To classify methods of illegal collusion detection, the first step is to divide them into categories based on the methodology of data processing. Statistical methods use econometric modelling or statistical inference in order to calculate the probability of the occurrence of an agreement impairing market competition. Indexing methods are called deterministic, focusing on individual signals or signal sets or on appropriate indexes allowing for the identification of the “dubious” markets. The superiority of statistical methods over indexing ones, claimed on the basis of the possibility of calculating the probability of market abuse, is mostly superficial. Firstly, statistical and econometric methods generate scores encumbered by many errors. Therefore, it is reasonable to treat the probability estimations with some doubt [15]. The main source of errors are differences in the functioning of a studied market and the markets of reference, in other words, the trouble of selecting an appropriate benchmark. Another market, the same market in a different period of time or other group of entrepreneurs (non-cartelists) operating in the same time as the market suspected of cartelization – all these may become markets of reference.

Another example of the source of error which may encumber the results of statistical methods are errors in the specification of a model or a statistical test, often caused by the restricted availability of data. Secondly, indexing methods often make use of statistical methods, e.g. the scores resulting from econometric studies might be utilized for the weighting of competition indexes. Moreover, such methods are based on economic theories and the information obtained from historic cartel cases. They also allow to establish the market classification with regard to the risk of illegal agreements’ appearance which makes them extremely helpful tools for screening tests.

3.2.2. Structural and behavioural methods

The type of a symptoms examined in order to detect illegal collusion is another criterion of classification. There may be symptoms concerning the features of the discussed markets (structural methods) or the behaviour of entrepreneurs (behavioural method) [22,31]. Structural features may result from the company’s behaviour or strategy to some extent, although they should derive from the sole nature of the market, namely, the character of the sector, its cost structure and demand. These are the features such as the level of market concentration, entry barriers (administrative, legal, R&D expenses and advertisement) or the level of market concentration on the consumer's side, the stability of demand, customers' churn numbers or the frequency of new companies' market entrance [15].

Economic theories, the conditions of the stability of cartels (or tacit collusions) in particular, indicate the structural features of markets conducive to the establishment of collusion agreements and the formation and operation of cartels. Behavioural characteristics refer to the behaviour of respective entrepreneurs, mainly pricing strategy and individual shares in the market. In case of bid riggings, they refer to the more widely understood tender behaviour. Regarding such methods, economic theories, as well as conclusions arising from the study of the previously detected cartels, are the source of identification criteria for behavioural patterns which are consistent with the existence of an illegal agreement, or which are more suitable for the hypothesis of acting in liaison rather than the hypothesis of independent business decisions. The choice between the structural and the behavioural methods is being made based on available data, for general advantages and disadvantages of these methods are difficult to unequivocally appraise.

3.2.3. Screening tests and in-depth research

Another important differentiating factor is the scope of the markets included in a study, examined by one specified method. Methods that use basic and easily accessible data allow for running screens and the examination of many markets [22,25,32]. Such studies are encumbered by potentially big errors. However, like in medical research, they allow for a preliminary selection on markets exposed to collusion occurrence. A good screening method is characterized by a low level of type II errors (negative result in case of factual abuse) but a high level of type I error might be accepted (a positive result in case of detecting a non-existent abuse) [15].

In-depth studies are restricted only to selected markets. The used methods usually are not suitable for screening tests, because they are too labour-consuming or dedicated only to a specified sector. Depth of the study, which narrows the range of errors in collusion detection is an advantage of such techniques. However, if there are multiple markets in the screening test and there is no a priori suspicion or evidence of abuse, in-depth studies require already existing suspicions towards the market. The main problem with in-depth studies is the demand for more detailed data, usually unavailable for the public in-depth studies.

Performing an in-depth study carries a risk of pre-alarming the entrepreneurs suspected of participation in the collusion, which naturally impairs the evidence acquisition during e.g. a sweep. Therefore, antitrust authorities use in-depth studies quite rarely, either only if high-quality data is publicly available (e.g. in case of regulated markets) or if there is no risk of pre-alarming the cartelists (e.g. the study's goal is to verify whether and when there was a neglect of a previously detected collusion). The ex post detection of cartels allows for development and evaluation of innovative methods used in the future.

4. Summary

Detecting anti-competitive agreements is difficult and requires vast interdisciplinary knowledge, experience, appropriate tool selection, availability of selected data, sometimes even a long term market observation [33]. The construction industry is particularly vulnerable for the occurrence of bid rigging (recurrent collusion) ([34,35]) and other types of anti-competitive agreements because of the high values of contracts and the existing structure of oligopolistic market. Such practices may occur both in tenders for comprehensive construction work contracts and in the production of building materials or equipment performance alone.

In order to successfully combat cartels and bid rigging in the construction industry, it is necessary to constantly improve methods of their detection, follow technical progress and develop new tools, using the previously unavailable techniques and resources. One of the new methods for anti-competitive agreement detection might be a scheme of electronic tenders for public contracts in the construction industry (e-procurement). In such tenders, the ordering institution would use the Building Information Modelling model (build formula) as part of the announcement or it would post a functional-utility programme forming the basis for the execution of the BIM model presented to bidders (design and build formula). On an electronic platform, the antitrust authorities could store data concerning each tender thorough the years and on an unprecedented scale:

- Records of the tenderers and ordering institutions (administration, location, ownership structure, subcontracting);
- Records of tenders (price and other criteria, winners, appeals, consortium establishment);
- BIM models (individual prices, bill of quantities, applied technology and materials).

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Such a properly designed and systematically updated database might be analysed through the use of artificial intelligence with an objective to detect irregularities - relations indicating the possibility of collusion. The analysis of the discussed relations may be applied for the determination of simple rules historically present in the database of construction tenders. This type of analysis allows for monitoring the association rules usually hard to observe in a huge database by the use of conventional methods, such as stating that if specified conditions are met, there is a specified variable option. For instance, if a tender has fixed parameters (framework = "road works" and price > PLN 1 mln and work location = "masovian voivodeship"), the following rule is fulfilled: the winner is entrepreneurship A, B or C. The analysis of relations allows for the observation that some of the tenderers win only in specific geographical locations, although they participate in tenders also in other regions. In this situation, standard guidelines publicised by antitrust offices may prove useful [36–38]. Data mining could enable the retrieval of much valuable data from the offers of selected entrepreneurs and BIM models themselves.

Artificial Neural Networks might be used for classifying tenders into different risk groups of collusion occurrence at the stage of preliminary tender results. Such a solution would make it possible for regulatory offices to quickly determine a group which should be put under scrutiny and to assign appropriate operational resources for the purpose of more precise examination. The theory of fuzzy sets can be successfully used for the classification of road construction tenders following the criterion of the possibility of anti-competitive agreement occurrence, which is presented in paper [4].

However, it is the application of artificial intelligence as well as the BIM data with aim to integrate the processes of electronic tenders, that might be another milestone for efficient detection and substantiation of collusions in the construction industry. Techniques of artificial intelligence may effectively determine mutual relations, normally impossible to observe by conventional methods in the short period of time, for they make use of the great amounts of seemingly uncorrelated data. It could be, for instance, determining personal capital ties, geographical variability of ordered contracts, market concentration, materials applied in specified locations etc. The author is currently conducting further studies on the development of such a system.

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A BIM Based Approach for Optimization of Construction and Assembly through Material Selection

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Abstract

During the design phase of construction projects, professionals seldom consider implications of design choices in terms of the ease with which it can be constructed. This contributes to wastage when chosen design features and materials result in the use of inefficient construction production and assembly methods. In order to bridge this gap, this study provides an approach for incorporating production knowledge and data into Building Information Models (BIM) to support optimization of building designs in terms of the efficiencies associated with their onsite production. A building design assessment system is developed to aid selection of alternative building design elements and materials in a digital prototype before they are actually constructed. The assessment system relies on an index derived from production knowledge or data related to ease of assemble, speed of assemble and the waste associated with the assembly or construction of a building element or material. This paper presents the identification and prioritisation of criteria for the development of the index for optimal selection of building envelope systems. The criteria were reviewed by an expert panel (n=25) who provided weightings of criteria importance through a voting analytic hierarchy process (VAHP). A schema for implementation through the extension of BIM with external assessment index logic is also presented. The practicality of the system as an indicator of the efficiency with which a design can be built or constructed, provides a solution for leveraging production knowledge and data to improve design in terms of its buildability thereby reducing waste associated with inefficient construction and sometimes redesign or late substitution of materials.

Keywords: Assembly; Efficiency; DFMA; Lean Construction; Building

1. Introduction

The access to practical information about construction production is important for building design development. However, this information is often absent or inadequate especially at early stages of design conception. Furthermore, design concept is commonly affected at the construction phase of building projects when production information becomes available. This often results in design changes, delays of construction activities and material substitution. According to Boothroyd et al. [1], the efficiency of production processes depends on the decisions made at early stages of design conception. With the adoption of BIM in construction, early stage decision making has been greatly influenced through visualization, clash detection, material quantity take-off and so on [2,3]. However, there is huge data deficit about construction and assembly processes to serve as basis when making early stage decisions [4]. This is due to the complexity of construction operations and the fragmentation within industry. Like BIM, lean construction is gradually closing these gaps of inefficiency with proposition of production methods that eliminate waste [5]. Through lean construction, reliable data can be generated from construction processes while continually improving and standardizing the processes [5]. Also, by adopting Design for Manufacturing and Assembly (DFMA) principles, production data can be used to improve the construction efficiency through early stage design optimization [6,7]. With the ability of BIM to integrate these principles, lean construction and DFMA have great potentials to create continuous improvement in the construction sector [5,7]. This study explored the principles of lean construction and DFMA to develop BIM-based assessment metrics for material selection at early stage design.

2. Literature Review

The efficiency with which building designs are accomplished depends on the quality of information on which the design decisions are made. Designs that are produced without adequate early-stage consideration of the method of construction often create inefficiency during construction [8]. This is the basis of design assessment for constructability [4]. In the manufacturing industry, DFMA and lean principles have been applied to ensure that product designs can support easy manufacturing and assembly of parts [1]. Recently, successful practices in the manufacturing industry are being adopted in the construction industry to meet up the productivity targets of the construction industry [9]. There is also more emphasis on adopting manufacturing principles in construction in order to minimize activities on site which tends to be less controlled environment as compared to factory conditions where manufacturing takes place [7]. It is therefore imperative that designers have the ability to assess the extent to which their designs incorporate these principles [6]. However, these concepts have not been significantly leveraged for the development of knowledge-based assessment frameworks to be applied in design despite the promise of BIM for delivering this [7].

"Lean construction" refers to the adoption of lean production principles in the construction industry and overall helps to reduce/minimize waste in construction process to achieve optimum value [5]. With lean construction, reliable production data can be developed during construction operations and used for design decision making and continuous improvement [5]. The focal point of lean construction is to eliminate waste/inefficiency in construction processes, standardize construction procedure and reduce unnecessary complexity in methods of construction [9]. Lean is therefore dependent on data related to the efficiency and waste associated with production and may include productivity indices, man-hours, machine/equipment productivity and usage rates and so on. Through BIM, this information can be embedded within the digital objects as additional information to support early stage design decisions. Also, DFMA principles are commonly focused on improving ease of manufacturing and assembly from early stage of design. This creates an opportunity to creatively align these principles to maximize the potential benefits through BIM [7].

Assessment of design constructability is common in the construction industry. Some studies used the multi-criteria approach for developing constructability assessment models because of the complex nature of construction [4,8,10]. Constructability assessment criteria from these studies include standardization, minimizing the number of components variations, preassembly engineering, transportation, installation and reviews of specifications. Design constructability can also be assessed based on cost, time, sustainability, safety, and quality indexes [11]. Akinade et al., [2] on the other hand proposed the use of BIM for assessing waste associated with deconstruction. Many assessment models have been applied to improve construction efficiency, however, DFMA and lean principles could be applied to further improve the attainment of theses efficiencies.

Das and kachanapiboon [12] recommended that assessment models should be developed in a way to enhance user-based evaluation and ensure flexibility. Also, assessment tools should use a multiple criteria and scaled grading approach to ensure the adequacy of assessment tools [2,6,12]. Lastly, it is important to integrate the assessment principles as an additional knowledge-base in/attached to parametric design authoring software such as BIM to ensure applicability and practicality [2,7]. These recommendations are applicable in developing an assessment approach based on DFMA and lean principles for material selection in BIM-driven design.

3. Methodology

A three-phase methodology was developed to achieve the aim of the research. In phase 1, following an in-depth literature review on the principles of DFMA and lean construction, assessment factors which could ensure construction efficiency at early stage were identified. These factors were reviewed and prioritized by a panel of experts in the construction industry using priority voting survey. At the second phase, the result from the priority voting survey was analyzed to derive weights for each assessment factor. Also, a scaled interval rating system was developed from literature, surveys, industry reports, building standards and regulations. The scale (0-5) was used to develop the assessment interval using both quantitative and qualitative parameters. At the final phase, the assessment index for a case study of four building envelope materials was implemented within BIM to guide the selection of material for the building envelop. The four materials considered for applying the computation logic in BIM were (a) *precast concrete;* (b) *brick;* (c) *prefabricated exterior insulation finish systems (EIFS) on a metal frame* and; (d) *concrete blockwork*.

3.1. Identification of Assessment Criteria

In addition to lean, principles five major methods of DFMA assessment criteria (which is mostly used in product design and manufacturing) were used as basis for the identification of important factors for design optimization. The most recurring factors from this review was size of parts, weight of loose parts and handling difficulty [6]. Other important factors include standardization of parts and connectors, equipment and plant requirement, workforce (productivity) requirement and so on. The identified factors were classified and reviewed for adequacy. Finally, a consolidated list of criteria was derived resulting in a list of 14 presented in the Table 1.

Table 1. Assembly Knowledge Factors for Design Optimization

Categories	Attributes	Design Principle	References
Ease of assembling parts	Connection between parts	Joints should be durable, reusable and multifunctional. Permanent joints that cannot be recovered should be limited.	[2,13,14,15]
	Connection to main building elements	Connections that require a wet operation such as mortar, concrete etc should be minimized. Bolts and nuts are preferable.	[2,6,13,14,15]
	Post-assembly secondary finishes	Design should limit the use of materials that require secondary finishes for aesthetics, durability or fire protection.	[2, 6,13,14,15]
	Standardization of parts	Designer should make use of opportunity to standardize parts and components to enhance mass production and repeatability	[6,13,14,15]
	Multiple material usage in production	Parts with composite materials should be avoided, material variation should be limited.	[2, 13,14,15,16]
	Geometric complexity of parts	Regular and symmetrical shape with adequate tolerance is desirable for parts design to enhance easy assembly.	[2, 13,14,15, 16]
Ease of handling parts	Number of parts	The number of building parts should be minimized as much as possible.	[1, 2, 6,7,14,15]
	Weight of parts	The density of parts should be within the efficient handling capacity of workers and machines to avoid fatigue, accident, damages and assembly errors.	[2, 6, 15,16]
	Tools and equipment requirement	Assembly operations that require the use of too many tools should be avoided, tools should be minimized. multipurpose equipment is preferable.	[8,12]
	Fragility of parts	Fragile parts that require special damage protection and handling should be avoided, parts should be compact and not loose.	[16,17,18]
	Quality control requirement	Complex parts that require expert quality assurance should be avoided unless necessary, design should enable easy quality control and less sampling.	[5,12]
	Number of workers required	The number of assembly workers should be minimized as much as possible through the design of efficient assembly system.	[5,12]
Speed of assembling the whole system	Speed of assembly in relation to labor and equipment cost	The efficiency of the assembly process is determined by the amount of work done with available resources. Efficiency should be as high as possible to minimize resource used and maximize work done.	[5, 13,15,19]
Waste produced during operations	Waste index of parts and applied finishes	Assembly choices with minimum material waste are preferable.	[2, 5, 13,15,19, 20]

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4. Development of Weighted Index for Assessment Criteria

In order to implement any index based on the factors above there is a primary need to weight the criteria in order of importance or contribution to assembly optimization. Thus, quantitative data about criteria importance was ascertained through voting analytic hierarchy process (VAHP) methodology. This was based on a panel discussion and voting survey targeted at experts with extensive knowledge in construction technology as well as offsite manufacturing methods. Although participants with vast experience were targeted, the survey questions were kept unambiguous and easy to respond to [21]. The range of expert experience spanned BIM, lean construction, offsite fabrication and materials. The respondents were purposefully targeted based on their knowledge of the research subject [22]. A total of 40 experts were invited with 25 valid responses received at the end of study. The job description of respondents included Architects, BIM Managers, Project Managers, Waste Managers, Mechanical and Electrical Design Engineers. The factors shown in Table 1 were ranked in order of importance relative to their contribution to most efficient construction. This ranking was used to develop the weightings for the multi-criteria assessment indices for assembly for the materials in the case study. The participants were required to cast priority votes for each of the assessment criteria as well as sub-criteria.

Table 2. Background of Expert Respondents.

		Frequency	Percentage (%)
Job Description	Architect	5	20.0
	BIM Manager	2	8.0
	Civil/Structural Engineer	6	24.0
	Construction Manager	6	24.0
	Mechanical/Electrical Engineer	1	4.0
	Project Manager	3	12.0
	Site Waste Manager	1	4.0
	Others (Lecturer)	1	4.0
Qualification	HND	2	8.0
	Bachelor's Degree	8	32.0
	Master's Degree	10	40.0
	Doctorate Degree	4	16.0
	Other	1	4.0

4.1. Weighting of Assessment Criteria Based on Expert Input

The expert priority voting survey was used to establish the relative importance of the 14 criteria for design assessment for fabrication and assembly. The prioritization presented relates to building envelop systems construction given this was chosen as the case material for implementing the proposed system in this study. The criteria were grouped into four areas namely, *ease of fabrication and assembly, ease of handling parts/components*, *productivity* and *waste generated*.

These criteria are used to develop the assessment indices to compare the relative degree to which the design options satisfy each criterion. Every valid response contained votes to rank the criteria position (for example 1st, 2nd, 3rd, or 4th). The sum of votes for each criterion is shown in Table 3. The weight of the criteria and sub-criteria was determined using Hadi-Vencheh and Niazi-Motlagh's [23] VAHP equation. The rank of each criterion was determined using these weights; "speed of assembly" had the highest rank, "waste generated" had lowest while "ease of assembly" and "ease of handling parts" have ranks 'second' and 'third' respectively.

The same procedure was used to determine the ranks of the sub-criteria. The normalized weights are obtained for the twelve sub-criteria, the sum of weights from each category is equal to one. The global weight for each of the assessment factors was determined by multiplying the weight of each sub-criteria by the weight of the criteria. These Global weights can be used directly as part of the computation logic is comparing different material types based on their performance and capabilities with respect to each of the 14 factors adopted for implementing this system. The performance and capabilities is assessed based on scaled assessment interval metric.

Table 3. Weighted importance of assessment criteria (***Wi***).

Categories	Weight (*Wi*)	Attributes	Weight (*Wi*).	Global Weight (*Wi*)
Ease of assembling parts	0.3184	Connection between parts	0.2898	0.0923
		Connection to main building elements	0.2057	0.0655
		Post-assembly secondary finishes	0.1165	0.0371
		Standardization of parts	0.1510	0.0481
		Multiple material usages in production	0.1088	0.0347
		Geometric complexity of parts	0.1282	0.0408
Ease of handling parts	0.2096	Number of parts	0.2101	0.0440
		Weight of parts	0.2882	0.0604
		Tools and equipment requirement	0.1426	0.0299
		Fragility of parts	0.1475	0.0309
		Quality control requirement	0.1069	0.0224
		Number of workers required	0.1048	0.0220
Speed of assembling systems	0.3216	Efficiency of operations	1.000	0.3216
Waste produced in process	0.1504	Waste Index	1.000	0.1504

4.2. *Development of Scaled Assessment Grading System*

A scaled interval was developed to assist designers in evaluating and quantifying the characteristics of each design options (materials). Based of multi-criteria decision (MCDM) modelling principles, the grading system is used in normalising the performances in each of the 14 areas for easy aggregation and comparison. Three methods of data development are used to develop the evaluation scale viz; (a) Existing literature and product information, quantitative and qualitative inquiry from experts; (b) Customisable inputs, which allows a designer in making a subjective user-based evaluation with respect to desired design requirement and; (c) The rule-based method which incorporates design and construction rules identified from the discussions with experts. The proposed structure of this grading/scaling system was also validated by the experts engaged in the study. For brevity, example of scales adopted for four out of the 14 assessment criteria is presented in Table 4.

Table 4. Examples of interval assessment scales (***Ci**,)* for grading individual building elements and materials.

Attributes	**Measure**	**Grading Scale Equivalent (*Ci*)** 0	0.2	0.4	0.6	0.8	1
Connection between parts	This attribute is evaluated based on Removability (R1), Reusability (R2), Stability (S_1), Standardization (S_2) and Dryness during operation (D). See Table Notes (a)	0	0.2	0.4	0.6	0.8	1
Degree of standardization	This attribute is evaluated by finding the percentage number of standard parts in total number of parts in the design options.	≤ 10%	11% - 25%	26% - 44%	45% - 65%	66% - 84%	≥ 85%
Weight of parts	This attribute is evaluated using the density and volume of part material. Equation provided within the system determines the computation of the relative weight of parts for scaled evaluation.	≥ 15.1 kg	12.1 - 15.0 kg	9.1- 12.0 kg	6.1- 9.0 kg	3.1- 6.0 kg	≤ 3 kg
Production rate	The production rate for each design option is assessed based on the quantity of work that can be completed in a unit labour-time. Mechanical equipment-time is converted to labour/cost equivalent.	≤ 0.5 m^2/man-hour	0.51 - 1.0 m2/man-hour	1.1 - 2.0 m2/man-hour	2.1 - 4.0 m2/man-hour	4.1 - 6.0 m2/man-hour	≥ 6.1 m2/man-hour

For brevity, we present below example of computation logic for the assessment criteria and overall index aggregation.

(a) The formula (Equation 1) below is used to calculate the grading value for building element relative to the attributes such as connection between parts (Attribute 1) and connection with other building elements (Attribute 2).

$$\textit{Type of Part Connection} = \frac{R1+R2+S1+S2+D}{5} \quad (1)$$

(Where $R_1=1$, *if the connector is easily removable without damaging connected parts and* $R_1=0$ *if connector cannot be removed without damaging parts.* $R_2=1$, *if connector can be reused if removed from assembly and* $R_2=0$, *If connector cannot be reused.* $S_1=1$, *If connectors require no temporary support after fixing to attain stability and* $S_1=0$ *if connectors require temporary support,* $S_2=1$, *If connectors are standardized and* $S_2=0$ *If connectors require special production specification.* $D=1$, *if the connection does not involve wet operation and* $D=0$, *If the connection requires wet operation).*

(b) The Formula (Equation 2) below shows how the composite index of overall optimal design is computed based on the aggregation of computations for each of the 14 factors with respect to each building element (material).

$$\textit{Composite Optimum Assembly Index Computation} = \sum_{i=1}^{14} W_i \times C_i \quad (2)$$

(Where W_i is the weighted importance of criteria *and* C_i, *rating point (i.e. 0 to 5) on grading scale based on material properties/performance).*

4.3. *Implementation of Assessment Logic in BIM for Design Optimisation*

The logic proposed is based on a comparison of different material options within a BIM (Autodesk Revit) environment with the aid of computations and knowledge stored in an external database (Microsoft Excel) relative to each material and its performance based on the grading scheme presented above. Open source, visual programming extension (Dynamo) is used to query basic information (i.e. material/element type and attributes such as geometry or quantities) from the Revit BIM model into the external database as demonstrated in Figure 2. The tools selected to implement the logic is as a result of its interoperability. For the experimental prototype developed in this study, four building envelope materials were used ((a) *precast concrete;* (b) *brick;* (c) *prefabricated exterior insulation, finish systems (EIFS) on a metal frame* and; (d) *concrete blockwork*. Comparisons of the performance of these materials in relation to the 14 assessment criteria, as well as an overall aggregate assessment (based on Equation 2) are then executed in the excel spreadsheets. The excel database contains all of the relevant indices for each material based on 14 assessment criteria which are normalized based on the interval scales proposed (see examples in Table 4).

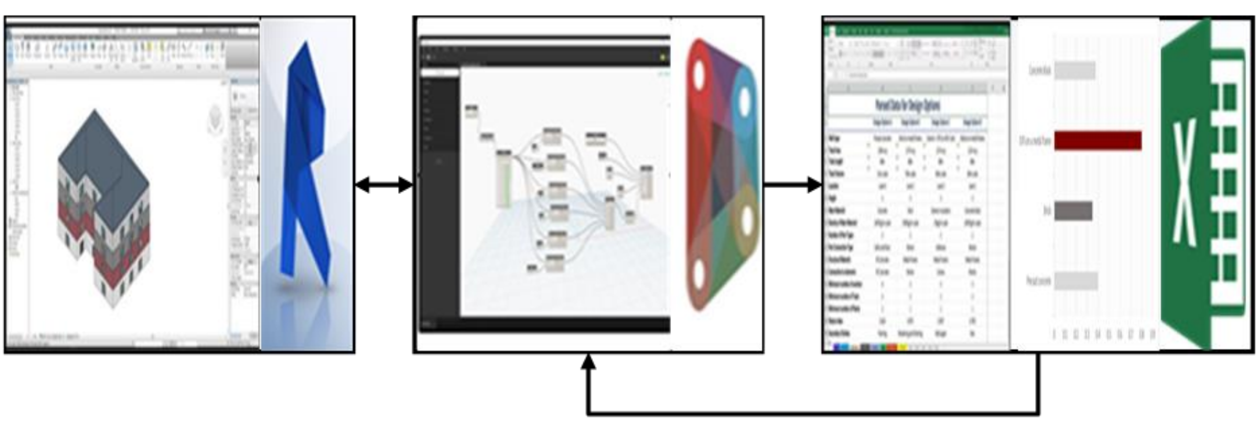

Fig. 2. Implementation of logic in BIM environment

The outputs from this is then interpreted using scripts written in Dynamo for visualization within the Revit environment. Designer can select which material or element types they require a comparison on in the database. For a comparison of any set of selected elements types or materials the best is highlighted based on a color coding protocol representing a range from the best to the worse alternative. Designers can also revise database as information especially on context dependent factors such labour productivity or plant availability. Existing element properties relating to geometry are relied on though this can still be altered in the database.

5. Discussion

An in-depth review of the literature revealed the lack of design optimization tools that are based on principles of successful practices in the manufacturing industry. The manufacturing industry is far more efficient than the construction industry because of best practices such as DFMA and lean production as well as their assessment [5,6,7,15]. Despite the proliferation of constructability/buildability [8,24,25,26], deconstruction [2,15], and waste estimation [2], none of such tools were based on principles such as DFMA and lean neither have they been developed from a perspective of design optimisation. Constructability and buildability assessments have also normally focussed on traditional construction processes where principles of offsite and DFMA or lean are not given the desired focus. From the empirical findings, factors related to speed and ease of assembly are regarded as paramount with the type of connections used to integrate building elements emerging as one of the individual most important factors. Similar criteria have been highlighted in previous studies [2,5,6,7,15,24,25,26,27]. In this study, it has been demonstrated that design can be optimised using information and data as a knowledge-base through its formalisation into assessment indices.

6. Conclusion

The aim of this research was to adopt DFMA and lean principles for the development of a design optimization method for construction. To achieve this aim, literature was reviewed to extract optimization factors for building construction and assembly. It was discovered that, despite the recent and gradual adoption of DFMA and lean in the construction industry, there has been no significant attempt to develop assessment metrics that ensure their integration with BIM to influence choices at the design phase. The factors were prioritised through a voting analytic hierarchy process (VAHP) as part of the development of an index for optimal selection of building envelope systems within a BIM environment. A schema for formalisation of this concept through the extension of BIM with the assessment logic is also presented. It is demonstrated that BIM can serve as a knowledge-base of production related information which can be leveraged at the design phase for lean and assembly optimisation. Future tools can evolve to cover other building elements in addition to building envelope, as well as fully automate the logic through developments of embedded plugins or programmes with the support of Application Programming Interface (API) of BIM tools.

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A comparison between different approaches for 5D BIM in construction site surveying

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Abstract

It is well known that BIM technology offers many profitable issues by now. Its benefits are widely experimented and described, especially in terms of design efficiency and interoperability. However, it is not so common, at least in Italy, to see projects completely managed by BIM, especially considering medium and small intervention. This approach should change in the next years while Italian laws will make mandatory, step by step, the use of BIM for public procurement of a certain amount. With the aim of the implementation of BIM in each phase of the project, also in medium and small interventions, the presented research examines the use of 5D-BIM during the execution phase of the process, to assess construction advancements during works with the support of modelling advantages. Then, the research focuses primarily on the definition of proper requirements to outline a 5D site management throughout the whole construction process. After the definition of different needs for the different actors of construction process, the research moved to the possible BIM use for the satisfaction of these needs by the definition of customized parameters dealing with site spaces and facilities, quantities, time and cost management. The study includes also the levels development (LOD) definition of objects aimed to the scope of using information contained in the model for the works advancements checking during the realization of works. An approach was studied to realize the scope of work, tested in different construction sites with the aim to satisfy both the needs of clients, and the needs of a contractor. The considered construction sites are similar in terms of dimensions and amount of works. As will be demonstrated in the paper, the on-field management with the use of models, if correctly developed and used, can simplify contractors and clients' inspectors job during the works realization in terms of efficiency of inspection and calculations.

Keywords: 5D; Building information modelling; Construction site inspections; LOD; Medium sites.

1. Introduction

The use of Building Information Models for construction design and management is spreading very quickly all over the world thanks also to the legislations which are now considering the advantages of such a method in each phase of the construction process. With the aim of underlining these advantages and translating them in the scope of the presented research it is useful to consider which should be the main aims of the information models.

One of the most known treatment about BIM uses in the whole building lifecycle is inserted in the BIM Handbook by Charles Eastman et al. [1]. Among the others, we can list some main aims of the models according to the phase in which this model is used or managed:

1. Model for the design of an intervention
2. Model for the management of the construction phase
3. Model for the facility management of the building

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Such phases are confirmed also by Succar's BIM framework [2] which defines BIM as "a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format throughout the building life-cycle". The lifecycle is identified in the three main stages expressed before, and it is valid for a certain number of models realized with specific aims such as structural or thermal analysis, architectural visualization, safety and maintenance managements and many others. Starting from this simple distinction it is possible to focus on the second one and on the model for the management of the construction phase.

1.1. Scope of work

The scope of work presented in this paper is indeed to provide a BIM-based workflow supporting clients and contractors in construction site surveying during works. It is well known that BIM technology offers many profitable issues that benefit owners, designers and constructors, especially in terms of design efficiency and interoperability. Moreover, it can become a powerful instrument for the client's team and the General Contractor all along the construction phase, starting from the construction site organization to answer the bid requests. It can also support the supervision of work progress and amount and allows to periodically reconsider them in compliance with available resources. Starting from these statements, the authors have developed some studies to obtain a systematic and methodological approach for site surveying and optimization. Then, the research focuses primarily on the definition of proper requirements to outline a 5D site management throughout the whole construction process. After the definition of different needs for the actors of construction process, the research moved to the possible BIM use for the satisfaction of these needs by the definition of customized parameters dealing with site spaces and facilities, quantities, time and cost management. The parameters have been identified to respond the needs of the on-field case studies analyzed. The first case studies concerned the realization of a residential building while the second concerned the realization of a school complex. The field tests permitted to refine the method also concerning the different disciplines of the building process. Both cases study concerned indeed structural, architectural and plants aspects proving efficiency and promptness to changes of the developed method concerning site inspections, scheduling optimization and visualization of works advancements. It is important to consider in this case that the modelling of objects do not represent, then, only the physical entity that will be present once the construction is finished, but also, if we consider the construction phase, the work to be realized during construction. Then the level of development of the objects needs to be managed according to the singe activities to be carried on during construction phase, and not according to the design needs. The site inspections here considered indeed deal with single components put in place in that instant of the construction and should be divided from the system which the component is a part. As an example, it is possible to consider a simple wall made by brick and plaster. In the construction phase such components needs to be considered singularly while the instant of their realization is very different.

The starting point of the research was then the study of the different levels of development standardized both internationally [3] and nationally [4]. Thanks to this study, together with on-field experience on different construction sites, it was possible to propose which should be the levels of development of construction elements with the aim of on-field work analysis. The research is evaluated using implemented tools in real case studies, two of which are here presented.

1.2. Literary review

Many authors suggest the thesis that a graphic visualization and management information system may incisively assist Project Managers in decision-making [5, 6]

The very last introduction of BIM technology certainly guarantees an improvement of quality, reducing time and costs [7] and is rightfully going to be compulsory in the design-bid-building process eventually. The latter insight is also supported by international administration trends that provide guidelines for using BIM in construction site standard, such as Finland standards Series 13, NYC Building Information Modeling Site Safety Standards and UK AEC BIM Protocol and the latest review of Italian law for public works (D.lgs 50/2016). Nowadays, several clients yet require the delivery of an as-built BIM model at the closeout stage. On the international stage, the interest in BIM technology has already been deeply ascertained. A survey conducted by Stanford University Center for Integrated Facility Engineering revealed the following results: up to 80%-time reduction generating cost budget with up to 40% elimination of unbudgeted change, and up to 10% deduction of the contract value through clash detection (CIFE Technical Reports, 2007). Suermann's survey, at the Facility Information Council National BIM Standards Committee, confirms that the major benefits derive from savings of cost and time requested for project completions [8]

While overall benefits concern the design phase with cost and time savings and communication improvement [9], BIM technology also provides great help in site management, and a BIM project is likely to be integrated with other KPI, especially regarding health and safety.

BIM automatically presents data both visually and analytically, information is clearer and easier to understand, and 4D models serve as platform for detection of potential conflicts and risk analysis [10]

Having observed that an intrinsic limit of 4D visualization in BIM models is the lack of economic features, we propose system to integrate BIM technology and EVM, following Haque [10] and Jrade and Lessard's intuition [11]. The basis of the study comes from the idea of Construction Site Information Model (Co.S.I.M.) and databases to focus on technical and operation information of construction site production elements [12]

Concerning digital models this paper will focuses on the objects Levels of Development (LOD) useful for the description of works realized. Considering LODs it is possible to say that can be described as the level of information quantities and specificity required for a element at a particular stage of the project. Then also in the modelling of an existing building, or of the works to be carried on it, it is very useful to manage information according to the stage in which the building is considered, adding further information if other stages are considered in different times.

Regarding Levels of Development state of the art is important to start any consideration from the existing standards on the theme developed internationally and nationally.

In this context of phases definition, a great importance is to give to the level of development of the model according to the phase in which the model itself is used. Definition of information contained inside BIM models is a matter of extreme relevance that cannot be entrusted. Without a set of rules, BIM models frame would vary depending on project complexity, its peculiarity and the amount of time reserved to modelling.

Level of Development (LOD) Specification is a reference that enables practitioners in the AEC Industry to specify and articulate with a high level of clarity the content and reliability of Building Information Models (BIMs) at various stages in the design and construction process. [13]

Starting from this point this paper analyses which are the minimum amount of information to be guaranteed to a digital model to manage the work advancement on site in a simple way and calculate automatically the amount of works carried on and related costs.

About works advancement control on site it is interesting to cite the work of Golpavar-Fard et al. [14]–[16] which try, among the other things, to integrate on site survey and scanning with automatic control of realized work. Other studies on site monitoring was made by Roh et al. [17] which use digital models for reporting construction progress thanks to interactive and visual approaches.

1.3. Research method

The context of this study is represented by a wider research considering the use of Building Information Models to design and manage construction activities starting from the first concept of the design stage to the construction phase of a building process [18]. Such a research is strongly related to on-field analysis and application. Developed methods and tools were in-fact continuously tested in real case studies to evaluate research and to refine it giving real applicability on site to the implemented theories.

The presented research takes into consideration indeed a solid background developed during years about construction site planning and management. It consists on some principles, in continuous development thanks to research on the topic, supported by many direct experiences carried out especially in relevant construction sites. These experiences permitted to get and remain in touch with the trends and developments of professional work to whom our research activities are dedicated. For this reason, our research method consists in a simple path that begins from the on-field observation for research development and returns at the end to the on-field application of the research. The research aims mainly to facilitate and make more efficient designers tasks in terms of on field work feasibility and construction site planning and operation. Thanks to the experiences given by a direct on-site observation is possible then to make a system between the developments of the research and the increasing needs of designers. This in order to develop methods and tools for enhancing efficiency to site planning and management of construction projects.

The field analysis permits also to have at disposal different case studies useful for testing implemented systems, evaluating their efficiency and, if necessary, refining them. Thanks to this approach we developed step-by-step many issues related to construction site design of construction project concerning also, especially in the last years, IT tools use and implementation. Thanks to this approach authors developed step-by-step many issues related to construction site design and management

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2. BIM approaches for on-field works analysis

As said the scope of work is the realization of an on-field work analysis with the use of a BIM. The first task is obviously the development of the model representing the facility. However, the realization of such a model is not so simple and the level of detail of its objects basically depends from a case to another according to the main aim of the model and to the other disciplines involved. Considering only the construction analysis and the site monitoring it is possible to say the level of development of the building model should be simplified compared to real representation and characterized by few information directly related to the work to be carried on. If we consider indeed a model realized for multiple purposes, such as design and facility management, it is possible to consider a different way of information insertion in the model. In order to simplify the dissertation, only information useful to construction analysis will be here considered, as if the BIM needs to be used only for that specific purpose. Starting from this point the main aim is to visualize, design and manage the works to be carried on and the related working area.

The level of graphical detail of the elements representing the works should be very simple for the presented purpose. It indeed to be associated, considering the AIA scale, to LOD 200 or 300. Considering instead Italian scale inserted in UNI 11337-4 it is possible to say that it is like LOD B or C. In this case the choice is to remain, in each phase of the project, to a low level of graphical detail, and increase, step by step, the level of development by adding further information useful for works analysis, advancement predictions and checking.

The proposed approach aims to enhance construction progresses analysis with the goal to avoid as much as possible accounting errors and to make more efficient future performances, according to collected data. The starting point of the analysis is, as said, the Building Information Model organized according to a Construction Breakdown Structure set up in line with the Bill of Quantity structure and the Work Plan. The output of this model, with the addition of cost analysis, is then a 5D model, to be managed during construction phase for advancements evaluation.

The system proposed is based on a pre-configured BIM template able to be used in each project and set with proper parameters that facilitate users in construction information management. Such a template is already set with objects related to the previously described LODs. Starting from this point the authors propose a methodological approach to assess project performance based on the percentage of physical work carried out, and to allow to periodically reconsider them in compliance with available resources.

3. Construction progress on-field monitoring

After the modelling of the objects with the approach explained in the previous chapter, it’s the time to understand how to use such a model during on-field checking. To do this some information need to be implemented in such objects in order to have at disposal on field a tool able to check the work without implying any further modelling effort.

The proposed approach aims to enhance construction progresses analysis with the goal to avoid as much as possible accounting errors and to make more efficient future performances, according to collected data. The starting point of the analysis is the Building Information Model organized according to a Construction Breakdown Structure set up in line with the Bill of Quantity structure and the Work Plan. The output of this model, with the addition of cost analysis, is then a 5D model of the works to be carried on, to be managed during construction phase for advancements evaluation.

In fact, such a model is realized to let clients and Project Managers to supervise the progress of the works during the construction phase and redact Building Progress Reports (BPR) according to what planned. At the same time, contractor needs such analysis for monitoring resource availability according to work advancements. The visualization and computation of the advancements is possible thanks to the parameters added previously in the 5D BIM (see table 1). The determination of any element is unique thanks to specific parameters related to the position of the elements (works) inside the building and the effective beginning-date and ending-date of the work. The model graphically shows, for a chosen time window, which elements have been realized and their position.

This task is made in the design phase to foresight advancements during future works and then compare them with the actual works simply updating the parameters related to the date of realization of the single elements. The BIM visualization and the information related permit to realize such updates in a very short time and directly on field.

Then, automatic BIM quantity take-offs, grouped under homogeneous Work Packages, automatically provide as output the percentage of physical work put in place against the total amount. The Project Manager should periodically update dates accordingly to works progress by monitoring the construction site. This way it is possible to check times and costs of the completed works verifying the progress of the planned Work Plan highlighting any delays or advances. The more frequent site inspections are (e.g., monthly or weekly), the more in-depth forecast solutions will be.

The information can also be stored into pivot tables (Microsoft Excel©), in which the realized quantities costs are fully itemized and grouped again referring to the work categories voices of the Bill of Quantity for the selected time window. Granting a total view over the advancement of the works, General Contractor monthly presents the partial bill to the client (BPR) and identifies the subcontractors to be paid. A proper organization of monitoring work, which can consider also supplier payment dates, allows the contractor to collect data for BPR and evaluate advancements according to resources availability.

Table 1. 5D parameters inserted in the model.

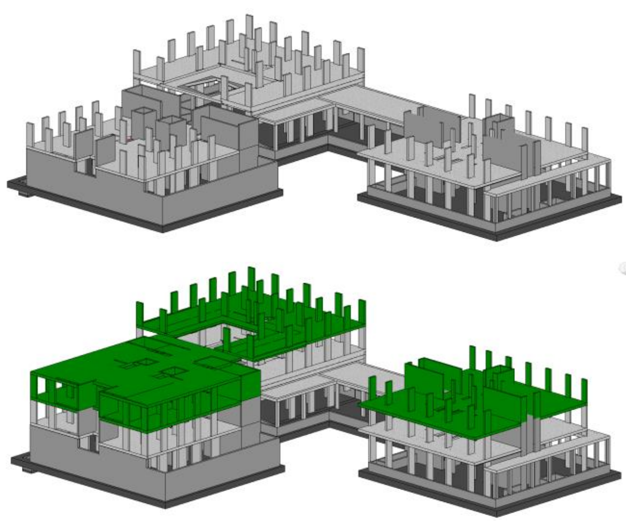
Element	Information
Technical element	- Quantity - Work programme ID - Beginning date - Ending date - Material cost - Manpower cost - Delivery charge - Bill of Quantity work category identification - BPR (number and date) - Activity duration

4. Case studies

The proposed method has been tested on real cases study, two of which are here presented. As said the first one consists in the realization of a residential building for university students. The research project concerning this case study concerning the use of BIM for construction and maintenance management. In this case the work of on-field analysis was carried on with the aim of helping the contractor to keep monitored costs of the construction site during works and to calculate the costs due to the subcontractors.

The monitoring process to produce the BPR started at the beginning of the construction phase and is updated weekly to see works progress. The updating of the model, once correctly set, resulted very simple and quick, so as also BIM new user can manage it. It is in fact necessary only to realize a site inspection for evaluating advancements and simply compiling in the model that specific parameters values related to realized items. Thanks to prepared filters and customized settings in the above-mentioned template, such a procedure permits to view the single monthly advancements and automatically takeoff from the model the quantities of the realized work.

Figure 1 shows the automatic filter of the works realized in a month considered compared to the previous month.



a

b

Fig. 1. (a) Visualization of the previous month; (b) Visualization of the considered months with advancements.

It is important to underline how both visualization and calculation of quantities related to the green objects, is automatic since the model is set to show in this way the elements specifically marked with the parameters of the advancement in an inspection. The graphic in Figure 2 summarizes the work progress by showing the comparison between the percentages of the considered month (light blue) with the percentages of all previous work (blue) for each identified work category. Such a graphic is automatically generated from the quantity takeoff generated directly from the BIM model thanks to the 5D parameters inserted.

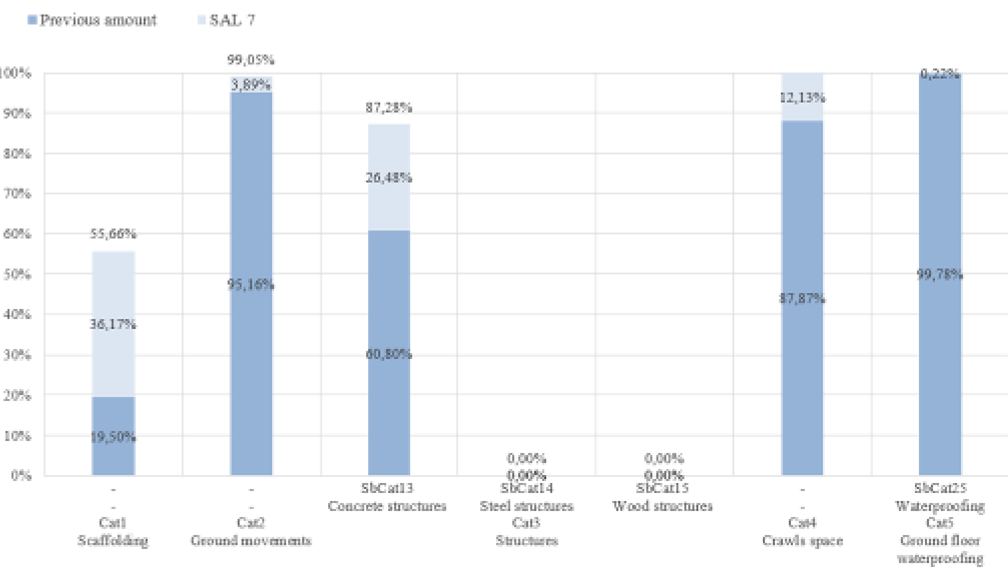


Fig. 2 Monthly work progress (light blue) related to the previous realization (blue).

Thanks to this approach, it was possible to create reports able so simply visualize and manage realized quantities in order to make simpler the dialogue of the contractor with its subcontractors.

A similar approach was used to another case study represented by the new construction of a school complex composed by two buildings. While these buildings are smaller than the first one, they are represented by some particularities due to the shape, the envelope and the plants.

As said, this second case study had the view of the client. It was in fact developed during a research project that involved the research team with the municipality that funded the project of the school. The aim of this project was the cost control during the works carried out by the client’s team in order to check the real progress of the works according to the budgeted cost.

Figures 3 and 4 shows an advancement like that showed in Figure 1 related to one of the schools of the complex.

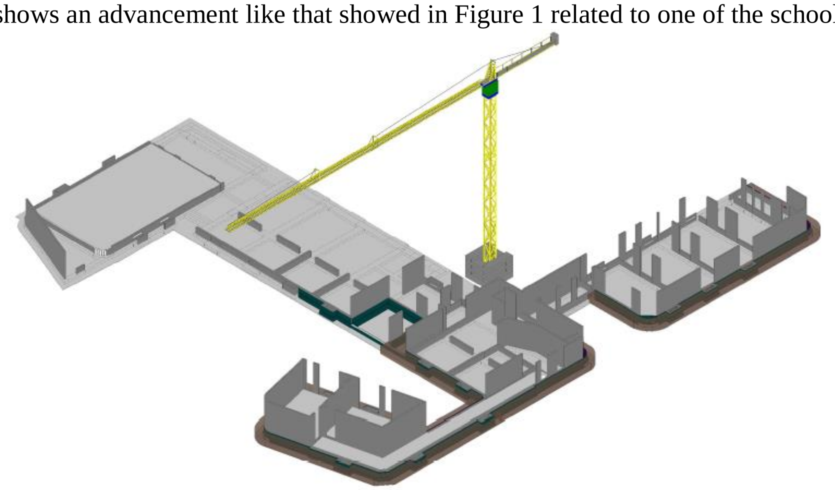


Fig. 3. Visualization of the previous month.

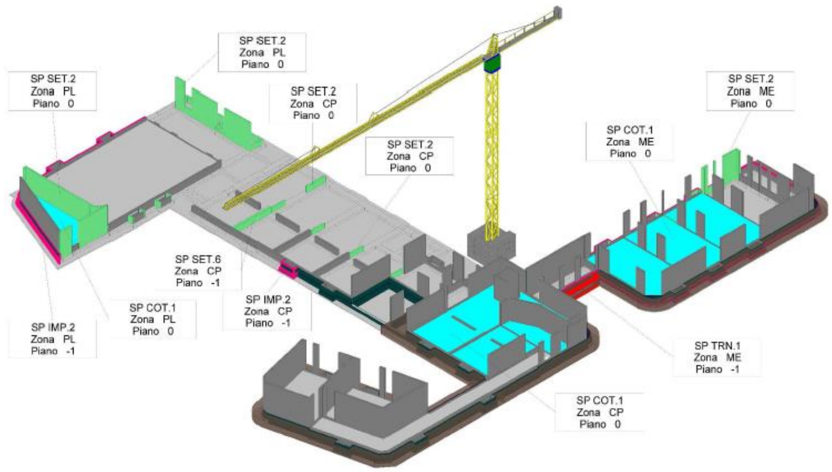


Fig. 4. Visualization of the considered months with advancements.

As visible, the visualization output was slightly improved in order to match the needs of the client's engineers team. The tags and colors match in fact the categories identified by the client during the design of the intervention. A particular approach was here used for the plants advancements identification. The peculiarity and the quantity of plants inserted in the model made very difficult to visualize their specific advancement month by month. Then the plant model was used for the 5D parameters and the quantity take-offs. However, to simplify the visualization was used the approach visible in figure 5. Each part of the plant is in fact represented by a colored cube filled with the exact percentage of the realized works. This view makes simpler and clearer the identification of the realized plants without representing them in their totality.

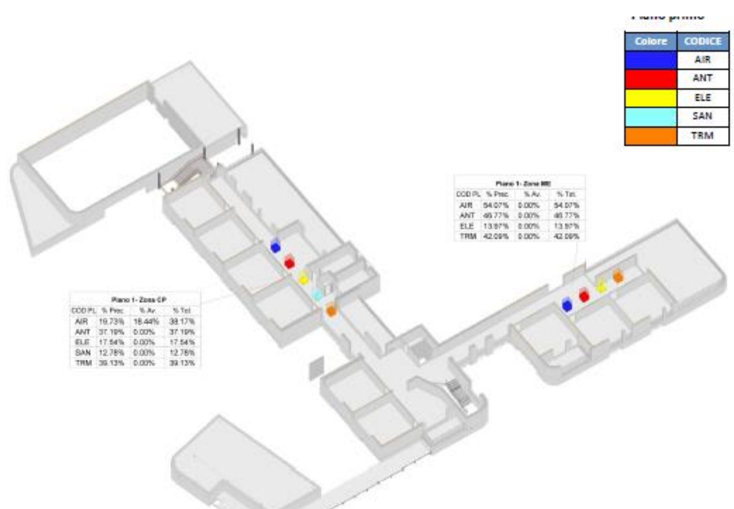


Fig. 5. Visualization of the plants advancements.

5. Conclusions and further developments

The two case studies showed how a similar approach can be used both to satisfy the need of a client and to satisfy the needs of a contractor. Both the studies aim indeed to the progressive quantity takeoff of the realized works and in the automation in produce reports useful for the client to check the contractors works, and useful for the contractors to simply match with its subcontractors. In any case the proposed approach satisfied the needs of the users concerning visualization capacities, simplicity of use and processing speed. However, such approach did not serve only the cost progress analysis. Such a BIM support permitted also to visualize the 4D advancement related to the 4D contract work plan, to visualize and evaluate delays compared to the design plan. Some simulations were made in this sense to use the parameters related to delay to re-plan the future works to avoid the same delays. This plan is made by modelling different construction alternatives for future works and visualize their related parameters of cost, time and safety. Thanks to the match of the parameters of the alternatives, based on the past parameters it is possible to choose the best solution in terms of times and costs. Only some simulations were made about this topic, but the first results are comfortable and put to continue to the research about construction options optimization.

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A review on Internet of Things solutions for enhancing construction equipment fleet productivity

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Abstract

The construction business is an ever changing industry facing increasingly bigger challenges, complexity and above all fierce competition. Contractors, in particular those managing fleet of construction equipment, have to cut their margins, increase the efficiency of their work force and assets, and control their total cost of ownership (TCO) to ensure an acceptable return on investment (ROI). As such, the business evolved in many ways to be cost-efficient. For instance, construction equipment manufacturers have focused on optimizing engine productivity, hydraulic versatility, and mechanical robustness, among many others. However, recent trends segued into delivering smart machines capable of reporting and adjusting equipment operators' behavior to achieve a better on-site fleet performance. This was made possible through the Internet of Things (IoT) and visualization tools by instrumenting construction equipment and devising advanced technological and on-board sensory systems as well as allowing the transfer of relevant information over a shared network within a 3D environment. The objective of this paper is thereby two-fold: (1) shed light on the latest approaches developed from tracking systems, load weighing systems, on-board operator assists to help equipment operators in spatial navigation, and (2) examine current virtual systems used to interactively visualize instrumented fleet of equipment and provide proactive on-site monitoring. The review revealed that there is substantial room for improvement and adoption of new tools targeted at reducing inefficiencies, improving fleet productivity, and producing higher quality results, in less time and with less effort.

Keywords: Construction Equipment; Internet of Things; Virtual Systems; Operator Behavior; Tracking; Sensing; Load Weighing

1. Introduction

In the last two decades, the construction industry has become increasingly competitive. This has thereby enticed contractors to continuously spend effort and resources on technological tools to advance their work and have an edge over their competitors. These technological advancements have been growing exponentially with the emergence of construction automation, Building Information Modeling (BIM) and lean construction [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. In fact, Information Technology (IT) is becoming a major part of construction project delivery and can, as such, greatly help in safeguarding the contractor's key project controls (i.e. time, cost, quality, and safety) as well as aid in risk avoidance and mitigation.

Among several IT advancements in construction (localization, BIM, Virtual Reality/Augmented Reality, 3D printing, cloud computing, etc. [11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21]), the Internet of Things (IoT) has emerged widely with several applications, in particular those related to construction equipment. These pieces of equipment require special attention and decision-making as they are critical and costly, be it the cost of buying or renting them, or the cost of monitoring, operating and maintaining them. In addition, equipment's productivity has a major impact on project scheduling and their use has an important safety aspect that needs to be monitored. As such, this paper

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aims at reviewing various studies that have applied Internet of Things (IoT) to enhance construction equipment fleet productivity.

2. Literature Review

The focus of the literature review is on papers related to IoT applications, primarily in relation to equipment in the construction industry or any potentially relevant industry. Table 1 is a review of 45 research studies related to the topic under study. For each paper, the application/industry is first identified then the objective, tools used, benefits and outcomes of IoT are presented.

Table 1. Summary of research studies relevant to Internet of Things (IoT) applications to Construction Equipment Fleet.

Reference	Application	Objective	Tools Used	Benefits and Outcomes
[22]	Transportation Engineering	- Perform vehicle surveillance	- ArcGIS Engine - Visual Basics (VB)	- Map control - Vehicle orientation - Special data query - Path programming
[23]	Construction Management	- Assess application areas of RFID in project management	- Radio Frequency Identification (RFID)	- Management of material, men and machinery
[24]	Transportation Engineering	- Monitor and collect statistics for Trucks	- Global Positioning System (GPS) - Wireless Sensor Networks (WSN)	- Real-time trucks output
[25]	Tower Cranes	- Improve crane operator performance with smart anti-collision assistance	- Proximity sensors - WSN	- Real-time crane position data - Decision-making support for collision avoidance
[26]	Mobile Cranes	- Create a comprehensive IT system to support mobile crane operation	- Sensors - WSN	- High precision data acquisition - High transmission speed - Facilitate remote monitoring - Accident analysis
[27]	Construction Safety	- Accidents prevention - Improve safety management in underground construction	- Fiber Bragg Grating (FBG) sensor system - RFID labor tracking system	- Real-time detection, monitoring and early warning of safety risks
[28]	Construction Safety	- Workers protection - Accidents prevention	- Radars and ultrasound sensors - General Packet Radio Service (GPRS) - Reading Equipment	- Ensure workers' safety - Advanced safety data collection - Reduce capital and operational costs
[29]	Road Repair	- Prevent accidents during road repairs by using robotic arms	- Robotic arm - Sensors	- Improved work environment - Enhanced safety measures
[30]	Construction Safety	- Establish a hazard energy monitoring system - Generate early warnings and alarms for hazard energy	- RFID - Tracking technology - Ultrasonic detection technology - Infrared access technology	- Achieve a safer underground construction site - Avoid unsafe behaviors for workers and equipment
[31]	Construction	- Develop a Smart Construction Object (SCO) and proactive big data management system - Facilitate the data collection, visualization and analysis for equipment management	- i-core sensor - Data warehouse software - Databases	- Normal equipment turned into smart construction equipment - Automatic collection of cost, environment and safety implications
[32]	Construction	- Address indoor localization of mobile construction resources	- Cloud enabled RFID - BIM - Remote monitoring	- Security control - Safety management - Asset management - Productivity monitoring

Reference	Application	Objective	Tools Used	Benefits and Outcomes
[33]	Tower Cranes	- Accidents prevention	- Sensors - Safety Equipment	- Reduced amount of wireless data transmission - Reduced energy consumption
[34]	Earthmoving	- Improve operation cost and productivity - Enhance automation and safety	- Sensing technology - Equipment tracking - GPS systems - Pattern recognition algorithms	- Equipment tracking and fleet management - Safety management - Remote/autonomous operation
[35]	Construction	- Machine visualization and identification	- Histogram of Oriented Gradients - Support Vector Machine - GPS and cameras	- Individual machine identification - No false positives due to the robust performance
[36]	Heavy Construction	- Integrating equipment management into existing simulation techniques.	- COINS simulation - Enterprise Mobility Management	- Provide learning through simulations for new employees. - Decision support for renting, leasing, and buying equipment.
[37]	Construction	- Measure the operational efficiency of construction equipment	- Machine Learning Algorithms - Accelerometers	- Different stages of machine operations are identified
[38]	Construction	- Quantify and analyze physiological data	- Physiological Monitoring Unit - GPS	- Framework for collecting and analyzing construction equipment operator's physiological metrics
[39]	Construction	- Recognize construction equipment and objects	- Deep convolutional network	- Monitoring of construction equipment in real-time
[40]	Construction	- Visualization of construction equipment in a model	- Finite state machine - Discrete-Event algorithm	- Real-time visualization and monitoring of construction equipment
[41]	Construction	- Vision tracking method using particle filters	- Real-time locating systems	- Track workforce and equipment movement on site
[42]	Cranes	- Develop operator-assistance system	- Motion sensors - 3D modeling - Point cloud	- Increase situational awareness - Improve operator performance - Improve safety
[43]	Construction Safety	- Proactively monitor site accidents	- Accelerometers - Distance sensors - Compass - Wi-Fi	- Mathematical formulation of three types of struck by accidents - Development of tools for site use
[44]	Construction	- Multi-Agent System (MAS) architecture that combines Location Guidance Systems (LGS) technology	- Near real-time simulation - Dynamic Equipment Workspace - Real-time locating systems	- Fleet automated guidance system
[45]	Construction Management	- Enhance operation productivity	- GPS - WSN - Web application	- Provide a guideline to managers - Effective equipment operations - Resiliency and flexibility improvement - Cost reductions
[46]	Tower Cranes	- Workspace 3D modeling - Collision detection - Offer visual assistance	- Wide-angle cameras - Laser scanner - Point cloud - Tracking loop	- 82-94% position accuracy - Enhanced situational awareness
[47]	Construction	- Detect and track construction equipment	- Video recording device - Object recognition algorithm	- Flexible system developed

Reference	Application	Objective	Tools Used	Benefits and Outcomes
[48]	Construction Safety	- Operator errors mitigation - Design operation-assistance system	- Inertial Measurement Unit (IMU) Sensor - Encoder sensor - Laser scanner - WSN	- Automatic hazard detection - Improved lift performance - Safer operation of heavy equipment
[49]	Construction Safety	- Reduced collisions between workers and equipment	- 3D point cloud - Laser scanner - GPS tags	- Provision of safety indicators - Pro-active decision support on personnel management, equipment selection and construction site layout design and planning
[50]	Construction Safety	- Develop a proximity detection and warning system - Enhance safety on site - Develop and test a real-time real time excavator control system	- RFID - Camera - Excavator control technology - Around View Monitor (AVM)	- Real-time control of equipment - Excavator accidents prevention - Hazardous proximity real-time detection
[51]	Construction Safety	- Construction site facilities prevention	- RFID - Directional antennas - Ultrasound waves - Radio transceiver - GPRS module	- Provide accident prevention system - Provide smart alerting system
[52]	Construction Management	- Analyze and measure construction equipment operation - Monitor project productivity	- IMU sensors - Smartphones - WSN - Dynamic time warping	- Automate the measurement of equipment cycle time - Increased measurement precision - Continuous productivity measurement - Automated data collection
[53]	Construction	- Develop a smart construction object-enabled proactive big data management system	- Smart chips - Sensors - WSN	- Provide concurrent decision-making information for equipment management - Enhanced data storage, processing and visualization - Cost savings
[54]	Construction safety	- Measure blind spots dynamically using the head posture of the equipment operator	- Laser scanning - Kinetic range camera - Point cloud	- Identification of potential hazards due to operating equipment next to workers - Enhanced safety on sites - Aid in the design of the equipment cabin
[55]	Construction	- Make informed fleet management decisions - Fleet use assessment - Monitor equipment health	- Transponder units - Code-Division Multiple Access - GSM - GPS	- Preventive equipment maintenance - Dynamic hazard function for each equipment type
[56]	Construction Safety	- Improve construction safety - Provide proactive real-time proximity alert	- RFID - 3D laser scanner - Equipment Protection Unit (EPU) - Personal Protection Unit (PPU) - WSN	- Support to equipment operators - Alert personnel of danger
[57]	Construction	- Recognize and track dynamic	- Cameras	- Improved productivity and safety

Reference	Application	Objective	Tools Used	Benefits and Outcomes
		construction equipment - Aid heavy equipment operation in perceiving 3D working environment	- Laser scanners - WSN - Data acquisition system	- Distinguish dynamic objects from static environment
[58]	Construction Management	- Provide an overview on new IoT technology and how they can be ported to construction sites	- NVivo software - Sensors - Data Mining - Cloud Computing - Digital porting	- IoT technologies update and development progress overview - Analysis of how methods can be sued together and applied
[59]	Construction Safety	- Using Sensor Based technology to enhance construction safety management	- RFID - WSN - Ultra wide band - Zigbee - Sensors	- Discuss the accuracy and usage of each technology - Provide a cost consideration in the studies - Mention the limitations and best application of the technologies
[60]	Mine Production	- Enhance underground safety and security - Improve work environment - Improve job quality - Improve work efficiency	- WSN - RFID and Object Identification - Sensors (chemical and biological) - Portable mobile devices - GPS positioning - Artificial intelligence	- Precise environment perception - Early-warnings for risk factors - Automatic identification - Precise positioning - Equipment management - Staff reduction
[61]	Transportation Engineering	- Improve route choice behavior	- Sensors and detectors - RFID - WSN and cloud computing - GPS	- Route tracking - Route guidance - Vehicle information tracking
[62]	Construction Management	- Improve the communication framework - Fully/partially automate communication functions across construction project lifecycle	- BIM (3D and 4D) - VisiLean - Cloud Computing - Visualization	- Enable lean and close to real-time reporting of production control information
[63]	Lean Construction and Supply Chain Management	- Present a cost-effective and easy-to-use web-based system integrated with RFID technology and Google cloud computing service that increases visibility and traceability of material and information flows of construction supply chains	- RFID - WSN - Google services	- Availability of real-time information - Assistance of computer simulation models
[64]	Electric Power	- Provide a Supervisory Control and Data Acquisition (SCADA) system for substations	- Servers and optical fibers - WSN and cable network - Sensors (temperature, humidity) - RFID - Cameras	- Equipment status monitoring - 3D visualization - Environment monitoring - Identify spare parts location - Asset management
[65]	Mine Production	- Improve decision-making - Improve emergency rescue situations	- Sensors and controllers - Camera - WSN	- Improved data monitoring and analysis
[66]	Oilfield Construction	- Production and management cost reduction	- LAN, Internet, 3G - Sensors, controllers and monitors - Cameras, GIS, GPS, RS	- Better digitization of oilfield construction

3. Summary of Main Findings

Following the review of 45 papers on IoT in construction and other related industries, it was found that the field presents diverse applications and uses, primarily in relation to construction equipment. Despite this diversity, common trends can be deduced. First, IoT requires the combination of two components, hardware and software, and the two are equally important. The importance of hardware lies in finding the right pieces needed to collect data from equipment and from the site as well as to transfer this data to the right receivers. On the other hand, the significance of the software component, together with designed algorithms, lies more in analyzing the transferred data to extract relevant information.

As previously mentioned, IoT revolves around information flow. In this case, all the reviewed studies had in common the following workflow pattern:

- **Data collection**: This is the first part of an IoT operation. The needed data is collected using mainly sensors (e.g. proximity, temperature, humidity, speed, etc.), GPS, RFID technology, OID, readers, cameras, transducers, etc. Other more advanced examples include drones and robots.
- **Data transfer/communication and storage**: Once the data is collected, it is shared with the concerned parties using various methods such as WSN, Wi-Fi, Bluetooth, 4G, cloud computing, etc. It goes without saying that the data needs to be stored in servers and databases.
- **Data analysis**: Once the data is transferred, it needs to be analyzed to become useful. This analysis is done using simple management concepts such as Earned Value Management (EVM) or using more developed tools such as developed algorithms, simulation models, Artificial Intelligence (AI), virtual models, etc.
- **Information and results**: Finally, following the three previous steps, results are generated converting data into valuable information that can support decision-making, result in warnings or provide any relevant information to the application at hand.

It was noted that many benefits can result from the use of IoT. These include improving workers’ understanding, visualization and awareness of the working environment including the present equipment and laborers. Another benefit lies in transferring information in real-time without delay, which can greatly smoothen the project workflow including project monitoring, tracking and control. Not only does the information transfer become timely, but it also becomes much more accurate. In fact, with all the new technologies and cutting-edge IT and communication hardware and software tools, the automated data collection and transfer can become efficient in reducing the error margins, thereby increasing information reliability and transparency and making it comprehensive and integrated across the project. Furthermore, the above enhancements related to information flow can positively impact the project performance as a whole, in particular its safety performance, as accidents can be potentially avoided through issuing early warning signs. Project management activities can also be enhanced by rapidly and efficiently collecting more data from jobsites and thereby reducing project cost and duration. Additionally, project work quality can be enhanced. Other benefits include waste reduction and reduced negative impacts on the environment. Most importantly, it can be concluded that this technology is very flexible and can be tailored to be user-friendly and easily accessible to all concerned parties.

4. Conclusion and Future Work

In this paper, several research studies that have applied IoT to enhance the productivity of equipment fleet in construction and other related industries were reviewed. However, it can be stated that the field has not been fully exploited yet. Other industries have yet to integrate their findings and contributions which would result in positive synergies. For instance, transportation engineering applications can greatly benefit equipment fleet management in construction. Moreover, applications within the same industry have yet to be combined to result in comprehensive IoT solutions. Such advancements can eventually lead to the full digitization of construction projects and sites, thereby making it possible for project managers and owners to ubiquitously access and visualize any part of the project with high accuracy.

Future studies will focus on designing integrated, thorough and comprehensive IoT solutions that can potentially maximize this technology’s benefits in relation to enhancing construction equipment fleet productivity.

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A system framework for RCM-based facility maintenance management in a park area

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Abstract

There is an increasing number of university campuses and science parks in China. The park areas usually have only one owner, but many organizations, for example, departments and companies, engaged in the facility maintenance management (FMM). These organizations usually are responsible for different disciplines in different facilities independently. Considering the fact that facilities influence each other most of the time, FMM performance for the entire area is thus unwarrantable. Therefore, we proposed a system framework for FMM in a park area based on Reliability-Centered Maintenance (RCM) and the integrated use of Geographic Information System (GIS) and Building Information Modeling (BIM). The requirement analysis was carried out and the system framework was designed. The system framework is valuable for developing software systems that can support multiple FMM organizations in an area to work on the same platform, avoid management problems and achieve better performance. A software system based on the proposed framework is now under construction.

Keywords: FMM ; Framework design; RCM; BIM; GIS;

1. Introduction

With the rapid development of education, science and technology in China, there is an increasing number of university campuses and science parks. They are a kind of estate, which is totally called a park area, and has multiple facilities but only one single owner. A park area usually covers a large consistent area where both horizontally distributed facilities, such as pipelines, and vertically distributed facilities, such as buildings, are located. Due to the diverse types of the facilities and different maintenance requirements from them, a park area is usually assigned to multiple organizations, for examples, departments and companies, for facilities maintenance management (FMM). The organizations are under the supervision of the administration of the park area but work independently by different disciplines in different facilities.

FMM in a park area is not just a summation of FMM in each single facility. From a physical point of view, it needs to take the interrelationships between facilities, and between facilities and their surrounding environment into consideration to identify all potential risks. From an organizational point of view, it needs to coordinate the divisions of work between multiple organizations to avoid overlapped or missed maintenance responsibilities. Without a dedicated information system, FMM in a park area usually involves two typical problems. First, for FMM organizations, they work independently without sharing information with each other so that it is likely to cause construction accidents. For example, Department A changes the depth of a natural gas pipeline in an emergency repair but tells no other departments. Later on when Department B does an excavation at the same place, there will be a high

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risk of leak accident because B has no awareness of the change of the pipeline. Second, for the administration of the park area, it is hard to guarantee maintenance reliability and cost-effectiveness of the entire area. This is because FMM managers usually work on their own, which may result in different levels of maintenance performance, whereas some could be very poor. Considering that facilities influence each other, maintenance reliability and cost-effectiveness of the entire area is unwarrantable in this way.

In Architecture, Engineering, Construction, Facility Management (AEC/FM) industries, Computerized Maintenance Management Systems (CMMS) have been deployed for (1) service request generation, (2) work order management, (3) required/used work resources calculation/tracking, (4) employees record management, and (5) inventory control [1]. Maintenance staff can use CMMS to upload and share maintenance information, such as drawings, documents and maintenance logs to ensure good information interoperability among the stakeholders. Nevertheless, there is still no CMMS applicable for FMM in a park area up to now.

Reliability-Centered Maintenance (RCM) is a systematic approach to evaluate a facility's equipment and resources to best mate them to obtain a high degree of facility reliability and cost-effectiveness [4]. RCM has been widely applied in military, nuclear energy, electric power, aviation, aerospace, shipbuilding industries [5], and some trials in residential buildings [7], historical buildings [8] and hospital facilities [9] have been conducted in AEC/FM domains. Nevertheless, how to apply RCM in FMM in a park area for maintenance optimization is still a problem to be solved.

The objective of this study is to propose a system framework for FMM in a park area based on RCM and the integrated use of GIS and BIM. This paper first reviews the literature of existing commercial systems and academic researches related to FMM and analyzes their applicability for the park area, then conducts the requirement analysis of the system. Finally the system framework is designed based on the integrated use of GIS and BIM and RCM method.

2. Literature review

2.1. Commercial system solutions

In AEC/FM, typical CMMS for FMM (FMM system hereafter for short) include FM:Interact [10], ARCHIBUS [11], AiM Facility Management [12], Maximo [13]. In recent years, commercial CMMS software has integrated technologies such as Construction Operations Building Information Exchange (COBie), Geographic Information System (GIS) and Building Information Modeling (BIM) for auto-generation of property and asset records, macro-level graphic visualization, work order mapping, bi-directional data exchange with BIM models [14]. However, existing commercial systems are hardly applicable in a park area for three reasons. First, they seldom provide automated analysis tools for maintenance planning and optimization, which multiplies the need for facility managers and professionals. Second, they do not support visualization of the entire park area in 3D graphics, which makes it hard to analyze the interrelationships between facilities, and between facilities and their surrounding environment. Third, they are designed for the case where the responsibilities for facility maintenance are taken by a single organization. If all FMM organizations in a park area work on this kind of system together, an organization will see or even be able to edit the business data of all the organizations, which is not safe. Therefore, existing commercial systems have limitations in the application for FMM in a park area.

2.2. Related academic researches

Currently there is no research reported about FMM system in a park area with multiple FMM organizations. Previous researches on FMM system can be divided into two categories, researches that realized the visualization of facility maintenance information, and researches that not only realized visualization but also business functions to support maintenance work flow, collaboration of multiple disciplines and optimization of decision-making. It is necessary to clarify that some researches used the term FM (Facility Management) but not FMM because they studied systems for general FM where FMM functions are included.

Regarding the visualization of facility maintenance information, Kang [17] developed a prototype system that could present related facility property data in the user's perspective based on the effective integration of BIM, GIS and FM data. Hu [18] realized a system that used a composite multi-scale BIM model to improve the 3D display efficiency in the operation and maintenance of mechanical, electrical and plumbing (MEP) projects. These researches improved information acquisition efficiency for maintenance staff.

Regarding the integration with maintenance work flow, Lin [19] proposed a mobile- and BIM-based FMM system which could provide easy access to basic maintenance information and maintenance records, generate maintenance forms for facility status updating, display facility status in 3D graphics and generate work reports automatically. Parsanezhad [3] devised a BIM-based integrated information web system that has functions for maintenance request send-receive. Xiao [20] proposed a mobile application framework of the BIM-based FM system under a cross-platform structure for on-site maintenance staff to query facility information and upload maintenance log. These researches improved the efficiency of maintenance staff.

Regarding the collaboration of multiple disciplines, Lee [21] implemented a web-based BIM interactive collaboration system for FM where users of multiple disciplines such as designers, FM managers and on-site staff can find required information, initiate a discussion and issue or arrange operation and maintenance tasks. The mobile app implemented by Xiao [20] could also support FM managers and on-site staff work in a unique platform. These researches helped maintenance staff achieve good information interoperability and timeliness.

Regarding the optimization of decision-making in FM, Hao [22] proposed a decision support system for FM that is intended to integrate and balance the employment proportion of different maintenance strategies to obtain a full-scale optimal maintenance program. Shen [23] proposed an agent-based, service-oriented conceptual framework that provided life-cycle information for decision making in facility operation and maintenance. Cheng [24] presented a decision support system framework based on BIM that utilized information from FM records to assess the condition of facilities, predict potential failure and develop optimized maintenance and budget allocation plans. In a BIM-based system framework, Chen [25] realized the automatic scheduling of work orders for facility maintenance. These researches helped improving the efficiency of decision-making, avoiding risk of catastrophic failure and reducing cost.

Although the research systems are powerful enhancement to solve many practical problems, they cannot be applied directly in a park area, due to similar reasons as stated for the commercial system solutions.

3. Requirement analysis of the FMM system for a park area

3.1. User analysis

In order to identify typical users and their requirements for the system, field investigations were carried out in Tsinghua University, BeiHang University and Lize Financial Business District of Beijing, in Beijing, China. They are all typical park areas. The field investigations includes two parts. First, interviewing with maintenance staff and managers. Second, collecting business documents, such as organization diagrams or maintenance forms.

The FMM in a park area runs on the collaboration of different functional departments and property management companies, whose managers and members are supposed to be the users of the system. The functional departments and property management companies, the relationships of them and the typical role settings in them are described by a three-layer organization diagram like Fig 1.

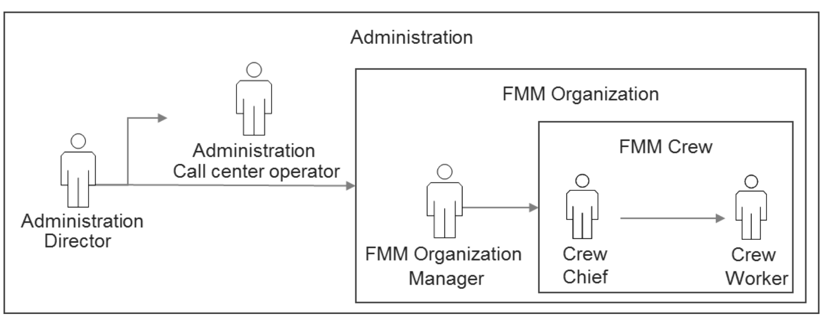

Fig. 1. Organization diagram of FMM in a park area.

The outermost layer of the diagram is the administration layer. Administration is on behalf of the owner of the park area to take charge of the overall FMM. There is only one administration in a park area. In this layer, there are two roles, i.e., the director and the call center operator. The former supervises the FMM performance in the park area and makes decisions on important issues. The latter collects and transfers service requests to the corresponding FMM organizations.

The next layer inside the administration layer is the FMM organization layer. FMM organization is the independent organization in charge of the FMM of certain facilities. There are many FMM organizations in a park area, in which there are FMM managers to do jobs like making maintenance plans and tracking the progress of maintenance tasks.

FMM organizations usually have their own crews to execute maintenance tasks, which are represented by the innermost layer of the diagram. A FMM organization could have more than one crew for different types of facilities, like electricity issues crew for power supply facilities and water issues crew for water supply facilities. In the crew, there are workers and a chief, where the chief is responsible for each task and workers take orders from him.

Arrows in the diagram represent a relationship of leadership. Generally speaking, crew workers receive orders from crew chief. The FMM crew receives tasks from managers in the same FMM organization and need to report to them. The FMM organizations are under the supervision of the director from the administration, where the call center operator also need to report to the director.

3.2. Functional requirement analysis

The functional requirements for the system come from each user's business processes of FMM and the needs to solve the existing problems, namely, the need to solve the information sharing problem and the need to apply RCM for maintenance optimization. As shown in Table 1, functional requirements from different users are summarized and divided into two categories, visualization functional requirements and business functional requirements.

Table 1. Function requirements from different users.

User	Layer	Visualization Functional requirements	Business Functional requirements
Director	Administration	3D browsing of the park area.	Maintenance plan approval; Maintenance performance assessment.
Call center operator	Administration	3D browsing of the park area; 3D browsing of facilities.	Repair task assignment.
Manager	FMM organization	3D browsing of the park area; 3D browsing of facilities.	RCM-based paintenance plan optimization; Maintenance plan creating; Maintenance task assignment; Task status tracking; Task result confirming.
Chief	FMM Crew	3D browsing of facilities.	Task result confirming.
Worker	FMM Crew	3D browsing of facilities.	Task result reporting.

Take the user manager from FMM organization as an example. A manager's duty in FMM is to create maintenance plans, assign maintenance tasks to workers, track the status of on-going maintenance tasks and confirm the results of finished tasks. When creating maintenance plans, as analyzed before, the manager should perform optimization analysis based on RCM. Thus, for the business functions, the manager requires the system to support RCM-based maintenance plan optimization, maintenance plan creating, maintenance task assignment, task status tracking and task result confirming. In addition, since facilities influence each other in a park area, the manager need not only focus on the facilities but also analyze the interrelationships between facilities, and between facilities and the surrounding environment, so the manager should require the system to support both 3D browsing of facilities and 3D browsing of the park area.

4. Framework design of the FMM system for a park area

4.1. FMM information model

Based on a detailed investigation of FMM in Tsinghua University, an information model is developed using the method proposed by Yu [26]. In this model, each entity represents real world objects, physical or conceptual, for the FMM in a park area.

As Fig 2 shows, the physical hierarchy of a park area is represented by four entities: 'Park', 'Unit', 'Facility' and 'Component'. The entity 'Park' refers to the type of estate that covers a large consistent area while the entity 'Unit' refers to each construction object whose functions are self-contained in the park area. A 'Unit' entity can consists of several 'Facility' entities. The entity 'Component' represents a functionally independent part in the 'Facility' entity. For example, in the case of Tsinghua University, the university campus is represented by a 'Park' entity while the laboratories and libraries are represented by 'Unit' entities. A library is facilitated by several buildings and maybe a parking lot, which are represented by 'Facility' entities. In the library, object such as a door, an air conditioner or a valve of a water supply pipeline is represented by the 'Component' entity.

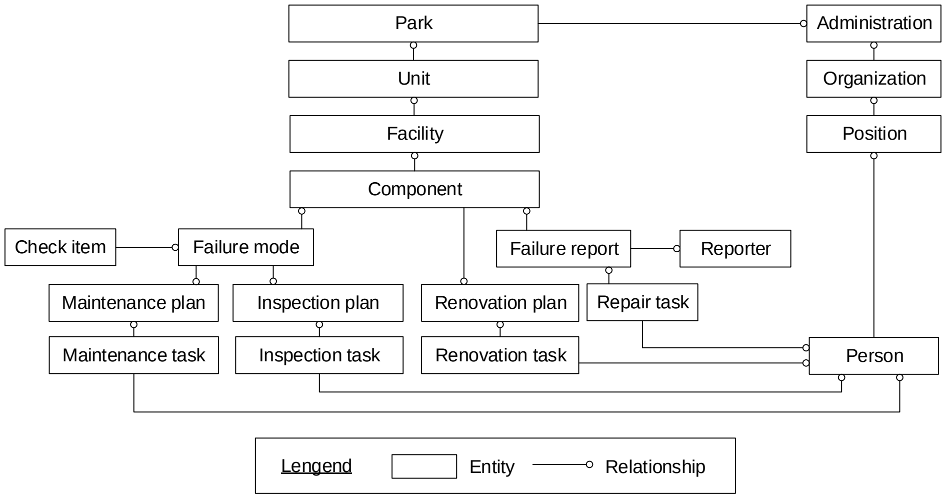

Fig. 2. Information model of FMM in a park area.

As explained in the organization model, the organization hierarchy of FMM in a park area is represented by three entities: 'Administration', 'Organization' and 'Role'. In addition, there is a 'Person' entity inherits the duty of the 'Role' to perform specific maintenance related works.

Strictly speaking, there are four types of facility maintenance activities in a park area, namely, maintenance, inspection, renovation and repair. Here, the maintenance refers to an operational and functional servicing action to maintain a component in good condition, such as cleaning the surface of a machine or lubricating a moving part. Each type of an activity has a 'plan' entity and a 'task' entity except for the repair. A 'plan' sets the instruction details and cycle of the operation. Every other cycle there will be a new 'task' generated and assigned to certain 'person'. There is no 'plan' for repair activities because failures of components usually happen suddenly and hard to predict.

Maintenance and inspection are actions taken to prevent failures in the facilities. The specific manner or way by which a failure occurs in terms of failure of the component function under investigation is defined using the term failure mode [27]. A component can have multiple failure modes. When making a maintenance or inspection plan, the manager decides what actions to take according to what failure modes would likely happen on the facility components. For each failure mode, there are several check items for occurrence detection, in which, two entities 'Failure mode' and 'Check item' are used to represent the concepts. As for a repair work, there is usually failure reports from reporters requesting repair services. This is represented by 'Failure report' and 'Reporter'.

By referring to this model, databases reflecting the actual data concepts and relationships for the FMM in a park area can be built.

4.2. GIS-BIM integration mechanism

In the system, GIS and BIM are integrated to facilitate the retrieval and visualization of multi-scale data, where BIM is used to create, manage and share the FMM data of vertical facilities while GIS is used to store, manage and analyze data describing the horizontal facilities and the environment of a park area. As Fig 3 shows, the front-side of the system is composed of three parts, a GIS viewer, a BIM viewer and a business information viewer, each has bidirectional data connection to the relevant databases in the back-side. Records among the three databases are linked by GUID of the facility or component, making it possible for users to jump between GIS viewer and BIM viewer. In the GIS viewer users can browse 3D graphics of the entire park area at low Level of Detail (LoD) and query macroscale data. They can also select certain facility and jump into the BIM viewer to browse BIM models of the facility at medium LoD. If necessary, user can also focus on certain component to see detailed geometry at high LoD with the rest parts being hidden. The business information viewer is always visible and shows business related information such as task information according to the use case. For FMM in a park area, planning and management affairs can be finished in the GIS viewer and BIM viewer while tasks can be executed only using the BIM viewer. Jumping between different LoDs provides flexible 3D visualization and good display efficiency.

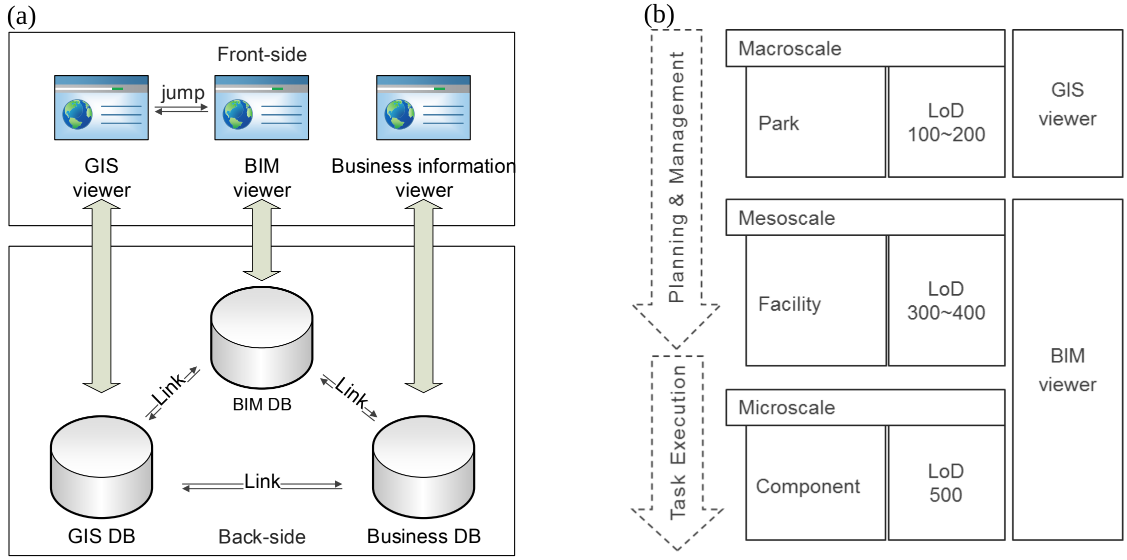

Fig. 3. GIS-BIM integration mechanism
(a) The technical architecture of GIS-BIM integration; (b) The schematic diagram of GIS-BIM integration for FMM in a park area.

4.3. Maintenance optimization mechanism based on RCM

RCM and Failure Mode and Effect Analysis (FMEA) are utilized for the facility maintenance optimization. RCM optimizes maintenance plan by prioritizing components of facilities and determining the appropriate type of maintenance strategies for them. There are mainly three types of maintenance strategies for facility maintenance, that is, the corrective maintenance (or reactive maintenance), the preventive maintenance and the predictive maintenance (or condition-based maintenance) [28]. Corrective maintenance is a simple strategy where a component in a facility will not get maintained until it breaks down. For this strategy, repair activity is mostly used. Corrective maintenance have the least life-cycle cost when failures seldom happen, but when emergency happens and causes a large amount of consequential damage to other components, the cost could be very expensive. Therefore, it is suitable for components with failures of low risk. Preventive maintenance is the strategy where maintenance tasks are performed in accordance with a predetermined plan at regular, fixed intervals to prevent failure occurrence at an early stage. For this strategy, maintenance activity is used. Preventive maintenance requires much labor and inventory for spare parts but can reduce the maintenance costs by avoiding the consequential damage. Therefore, it is suitable for components with failures of high risk and large occurrence probability. Predictive maintenance differs from preventive maintenance by basing maintenance need on the actual condition of the component rather than on some preset schedule. To initiate the preventive maintenance, the condition of a component must be monitored to identify whether there is any evidence of change from a normal condition to an abnormal condition. Inspection and sometimes sensors are used to monitor the condition. If a change representing an abnormal condition in the monitored parameter happens, a repair activity might be required. As we can see, predictive maintenance requires the most maintenance resources, so it is suitable for components with failures of extremely high risk.

FMEA is an engineering technique used to define, identify, and eliminate known and/or potential failures [29]. In FMEA, the Risk Priority Number (RPN) is calculated according to the effects, causes and detectability of each failure [30]. The calculation of the RPN is as follows.

$$RPN = S \times O \times D \quad (1)$$

In this formula, the parameter "*S*" refers to the severity of the failure mode, the parameter "*O*" refers to the possibility of occurrence of the failure mode and "*D*" refers to the detectability of the failure mode before it reaches the occupant. The value range of each parameter is from zero to ten.

For the maintenance optimization, FMEA is used to get all the failure modes of a facility component and calculate their RPNs. Prioritization of the components is performed based on the value of their largest RPN. Using the theory of RCM, assigning inspection plans to components with failure modes of large RPN, assigning maintenance plans to components with failure modes of medium RPN, and waiting for components with failure modes of low RPN to break then taking repair tasks will achieve the optimization of facility reliability and cost-effectiveness.

4.4. System architecture

The architecture of the proposed system is composed of four layers as shown in Fig 4. The top two are the Presentation Layer and the Business Layer. The Presentation Layer have a FMM Portal for the access from PC and a Mobile APP for the access from mobile phones or tablets. The Business Layer has nine modules to support different parts of the FMM in a park area. Inspection Management module, Maintenance Management module, Repair Management module, Renovation Management module and Failure Report Management module each supports the work flow of the corresponding maintenance activity. In Permission Management module, users create organizations and allocate information access permission to them. Similarly, in User Management module, users create roles and then allocate function access permission to them. In Performance Management module, users check the maintenance performance of each organization and crew worker. In Model Management module, users upload, update or delete BIM/GIS models for facilities or the park area.

The bottom two are the Service Layer and the Data Layer. The Service Layer provides shared functional services such as connection to the databases, GIS/BIM data presentation and user's location calculation for the Business Layer. The Data Layer, which is actually composed of databases, models, business attachments and system configuration files, is a very important managerial asset to the FMM in a park area.

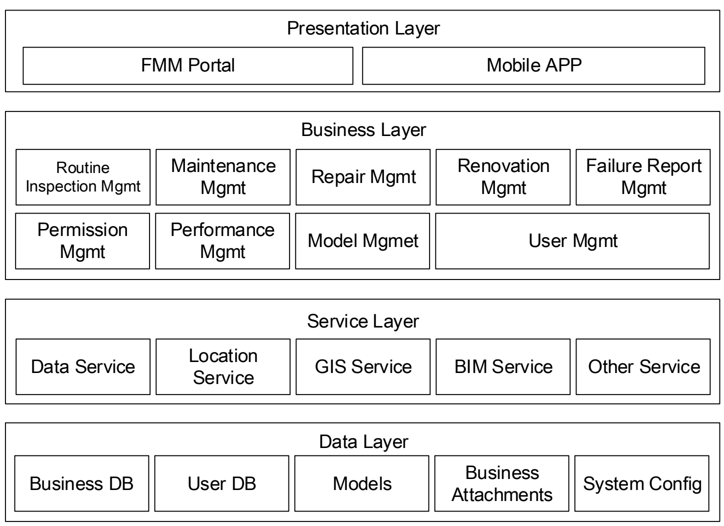

Fig. 4. Architecture of the proposed system.

5. Conclusions

The purpose of this study is to propose a system framework for FMM in a park area that solves two managerial problems, i.e. "poor information sharing between participating organizations" and "maintenance reliability and cost-effectiveness of the entire park area is unwarrantable". Through requirement analysis, this paper established a solution consisting of an information model for FMM in a park area, a GIS-BIM integration mechanism, a maintenance optimization mechanism based on RCM to formulate the system framework. The system framework is valuable for developing software systems that can support multiple FMM organizations of an area to work on the same platform, avoid managerial problems and achieve better performance.

A software system based on the proposed framework is now under construction. Future works of this study includes (1) designing the algorithm for the calculation of RPN, (2) integrating sensor data to support real-time condition monitoring.

Acknowledgements

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Application of 4D CAD System for Infrastructure Projects with Construction Schedules and Distance Coordinates

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Abstract

The typical constraints in expressing the current construction status of railway and road construction projects in a 4D CAD system are the complexity of creating 3D objects for many earthworks and non-repetitive processes. Also, since most of the work is done in a linear pattern in a horizontal work space of several tens of km, there are some parts that are difficult to express by the commercialized 4D CAD system oriented on the building project. In the activity management of the railway construction, most activities such as earthwork, bridge, tunnel, and catenary line except railway station are managed by the distance of linear axis. In other words, a methodology is required in the 4D CAD system to grasp the distance coordinates of the activity in addition to the construction schedule even when 4D objects are implemented. In this paper, the authors propose an automatic transformation method to linear schedule chart of Gantt chart expressed in a 4D CAD system, and propose a methodology for specialized functions of 4D CAD system which converted linear schedule chart and 4D object are interlocked.

Keywords:infrastructure project; linear schedule chart; Gantt chart; 4D CAD ;

1. Introduction

Building construction project consists of repetitive works in a narrow space with a vertical work pattern. On the other hand, the civil engineering project is working horizontally, and work is carried out with non-repetitive works in a wide working area. This feature is the reason why the application of BIM in civil engineering project is relatively small compared to the building project. In addition, since the civil engineer project includes many earthwork tasks, it is more difficult to represent the work objects in a three dimension. Although it may be different depending on the type of construction project, the importance of the design stage is larger than the construction stage in the building construction project, and the civil engineer project has a greater importance in the construction phase. For this reason, 3D modeling and interference management at the design stage are important functions for the application of BIM to the building project, and schedule management at the construction stage can be used as an important function for the BIM application of the civil engineering project. In other words, BIM application of civil engineering project can be more easily utilized in the construction management function by 4D and nD CAD.

4D CAD systems used for construction schedule management integrate the construction schedule and 3D design plan to sequentially visualize the completed form of the facility and provide real-time visualized site information to the participants of the construction project. Using a 4D CAD system, the completed form of a facility can be sequentially displayed according to the schedule of planned activities. Through this, the construction work can be reviewed in advance before the construction phase in virtual reality, which can be used to carry out schedule error reviews in the planning stage and constructability and interference evaluation for the facility in advance. Thus,

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constructability for each actual site can be improved through simulations using 3D objects according to the schedule. 4D systems can be utilized as a tool to facilitate communication between construction participating parties for solution establishment and prevention of constructability reduction between parallel tasks.

Various studies on BIM have been conducted. The main contents of this study are composed of 4D CAD related matters, so the existing researches are also examined based on 4D CAD operating system. Leon (2016) proposed a 4D CAD based method to support coordination of subsurface utility works. Christopher (2018) suggested an interior activity state recognition framework with BIM-registered image sequences. Kang (2013) presented a methodology and system development methodology for 4D CAD operating system specialized in civil engineering project. Moon (2015) suggests a systematic methodology and computer system for an optimal construction schedule simulation that minimize overlapping activities using 4D CAD system. Chin (2008) developed a progress management system that links RFID technology and 4D CAD to steel structures for efficient logistics support and construction management. Ashwin (2010) proved the usability of 4D CAD by quantitatively and statistically analyzing 4D CAD cases applied to practical work in order to improve the practical use of 4D CAD. Timo (2008) suggested a way to analyze applications of 3D and 4D models through past cases and apply them effectively in practice. Russell et al. (2009) developed a 4D CAD system that can efficiently perform construction management tasks considering linear scheduling of high-rise buildings.

As the utilization of 4D CAD system is more active in the building project, many related researched are also applied to practical application such as interference management of building works. As the application of BIM technology is expanded, applications of AR technology are also being announced. In this case, the researches on the construction of 4D CAD function, which is composed of linear activity processes in the horizontal working area, are not enough. This study attempts to develop a function suitable for the simulation of a construction schedule consisting of linear space such as road and railway projects.

2. Necessity of function improvement for existing 4D CAD system

Various commercially available 4D CAD systems currently used in practice are all centered on the schedule simulation functions in a vertical work space. In other words, since it is used mainly as a function of time-based schedule simulation function, it lacks practical progress management function and lacks other decision-making functions. The following functions for 4D CAD system are necessary to obtain practical use applicability in the construction phase of building and civil engineering construction projects.

- Intuitive progress management system: Provision of simulation information is necessary to intuitively determine the actual progress in comparison to the established schedule by comparing real video data such as that from CCTV installed at the construction site and smart phones with 4D objects.
- AR object integration function: Activities simulated with 4D objects are images expressed using VR (virtual reality) type computer graphics, and as such there is a discrepancy between the images and the actual site. In order to minimize this discrepancy, a simulation function that integrates AR (augmented reality) objects to the actual site image is necessary. By simulating the current activity progress image to six months into the future and its completed form one year into the future through integration with AR objects, the discrepancy between the 4D object and the actual site can be minimized for the field practitioner.
- Decision-making support system: There is a need to include decision-making functionality that provides activities optimized to the project through integration of analyses of the conventional 4D simulation functionality and risk information, minimization of schedule and workspace overlaps, and optimization functionality including cost optimization. Such functionality minimizes the overlapping schedule in the work zone without changing the total construction time to compare schedules with possible constructability improvement for selective application. Thus, the functionality can be utilized as a useful construction management tool.

3. Schedule management characteristics for construction project with linear work section

For construction project with linear work section such as roads and railways, there are many activities that are conducted simultaneously and modifications of manpower and equipment for the construction are necessary depending on the surrounding environment due to external operations. Thus, an activity management solution for linear projects is needed. However, although the conventional network method and bar chart are efficient methods of activity management for repetitive activities and limited workspaces, these methods are not appropriate for the management of linear projects, such as roads and railways, with construction sites that span tens of kilometers and include a lot of earthwork. Fig. 1 shows the 3D modeling of the earthwork operation for specific intervals (generally station number) from the starting point to the end point of a railway roadbed construction, which is carried out horizontally.

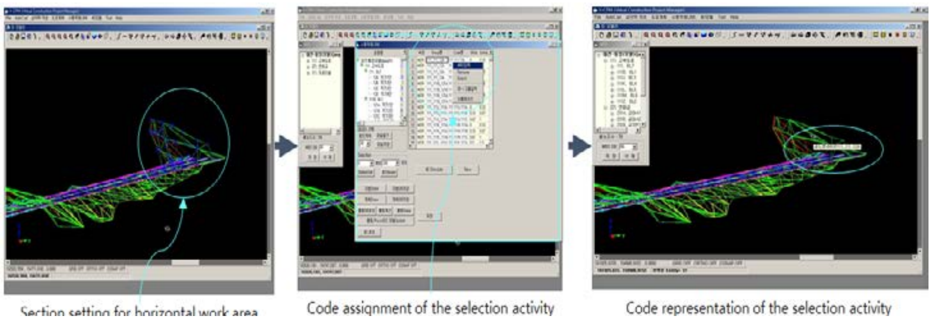

Fig. 1. 3D modeling for earthwork activity

The application of 4D simulation is more widely utilized in building construction compared to civil engineering projects, which can be attributed to the greater effectiveness of 4D simulation in terms of establishment and operation since construction work is generally carried out in a relatively vertical manner and is composed of repetitive activities in a small space. On the other hand, in the case of linear facilities such as railways, activities are carried out horizontally and mostly non-repetitive activities are conducted for the construction in a wide workspace, and thus the establishment and operation of 4D simulation is relatively difficult compared to building construction.

In addition, the schedule analysis system used in 4D CAD system is represented by bar chart or Gantt chart. However, while the conventional network method and bar charts are efficient for the activity management for repetitive activities and limited workspaces, such methods are difficult to implement for the management of linear projects such as railroads and roads with construction sites which span tens of KM. Therefore, it is necessary to integrate a schedule chart representation function specific to the representation of linear activity into the 4D CAD system.

4. 4D modeling for construction project with linear work section

While a location and schedule data integrated linear project activity management tool (TiLOS, Fig. 2) has been developed and is being used to supplement the existing activity management method for linear facilities, the tool is simply a 2D-based activity management tool that does not provide a visually convenient overview of the detailed location and progress of actual work. Therefore, activity management functionality specialized for linear facilities and a 4D simulation implementation solution is necessary for efficient activity management of linear facilities. For this, an activity management module development methodology, where the location data, schedule data, and their 4D simulation implementation are visualized, as shown in Fig. 3, is proposed in this study. The proposed methodology amplified the advantages and compensated for the disadvantages of the conventional activity management method and 4D simulation, and the methodology is expected to provide an innovative activity management solution for linear projects.

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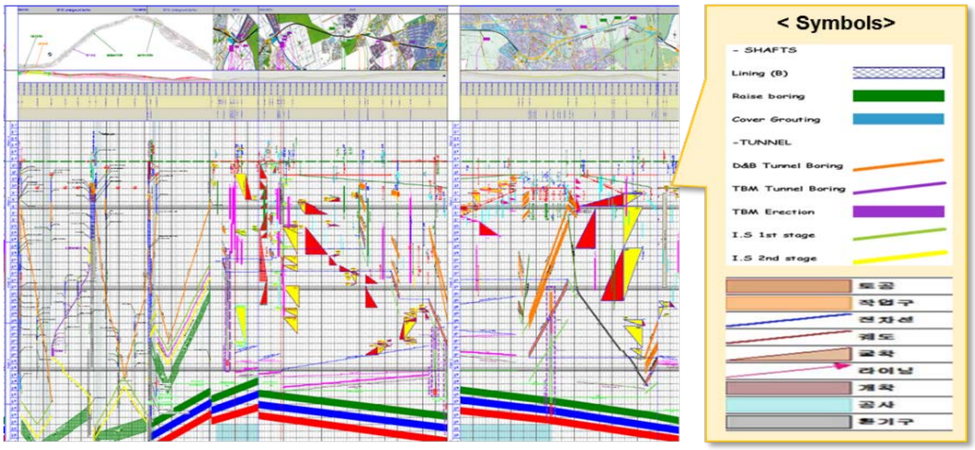

Fig. 2. Example of location-based milestones for railway project (TiLos, 2016)

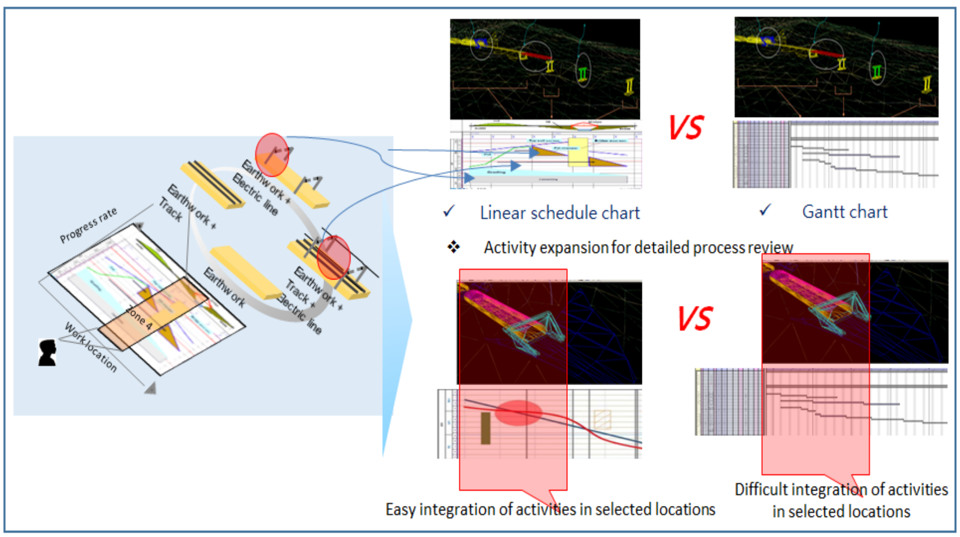

Fig. 3. 4D modeling for linear work sections

The schedule chart represented in the existing 4D CAD system is generally composed of Gantt chart. For the 4D CAD simulation with Gantt chart, showing a simple Gantt chart form of the construction schedule while showing the 3D completed form on the upper portion, as presented in Fig. 4, decreases the practical usability as the distance coordinate for each construction schedule cannot be displayed. To overcome this disadvantage, Fig. 5 shows the linear schedule displayed on the lower portion of the system monitor. The linear schedule simultaneously shows the progress location (X-axis) of each corresponding activity according to the construction schedule (Y-axis) along with the 3D completed form on the upper portion.

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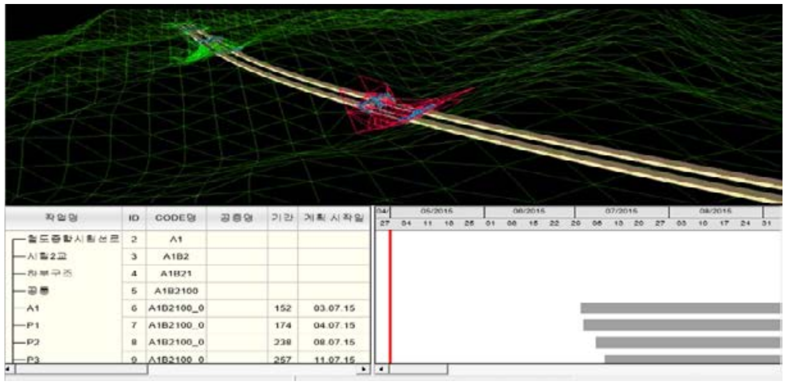

Fig. 4. 4D CAD simulation with Gantt chart

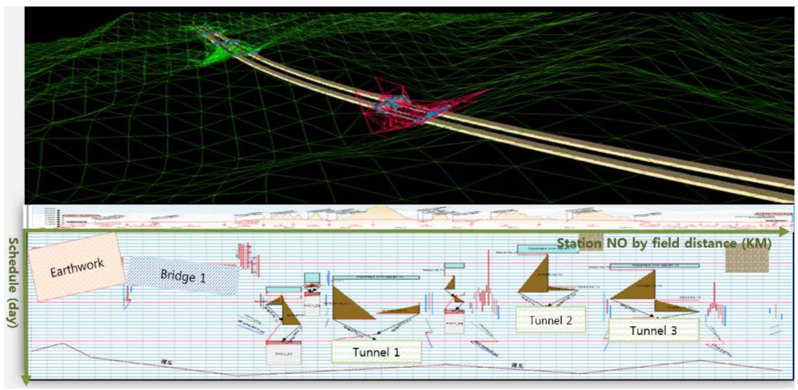

Fig. 5. 4D CAD simulation with linear schedule chart

In the linear schedule-based 4D CAD system, the work location within the project range of the corresponding activity can be simultaneously expressed according to the construction duration carried out in the lower portion linear schedule when 4D objects are simulated on the upper portion. Thus, the location of the corresponding activity in the linear workspace spanning tens of kilometers and the 4D simulation objects according to the construction time can be simultaneously identified for a linear project, allowing for efficient activity management. Therefore, in order to represent the linear schedule chart, the start and end position information of each activity should be included in addition to the construction schedule information of the project, and the shape applied to the actual project is shown in Fig. 6.

Fig. 6. Input data for schedule activity (including location information)

5. Horizontal activity representation in linear schedule chart

For the implementation of location-based 4D simulation, the activities composed of horizontal tasks need to be generated into a location-based schedule. For the production process of the location-based schedule, as shown in Fig. 7, the start schedule, end schedule, start location, end location, and X-axis reference point were inputted after determining the geometry for the corresponding activity. Based on these input data, the geometry for the corresponding activity is produced on a bar chart. For the location of the geometry generation on the bar chart, the front tip of the corresponding geometry is located at X-axis = start location and Y-axis = start schedule while the rear tip is located at the X = end location and Y = end schedule. The X-axis location data were made so that they were automatically converted to reflect the user inputted X-axis reference point.

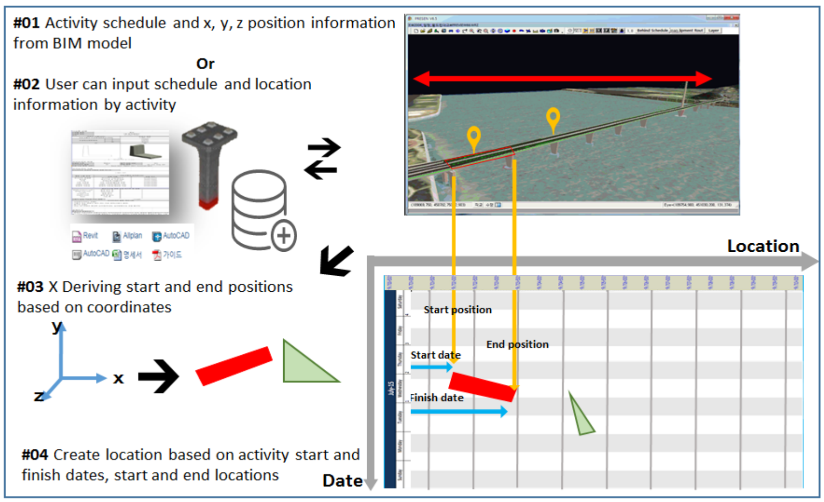

Fig. 7. Location-based linear chart generation for horizontal work process

When the location-based schedule is generated, it can be used to carry out the 4D simulation. The 4D simulation integrated with the location-based schedule is composed of the Y-axis schedule, unlike the conventional Gantt chart schedule. Hence, the “current progress line” moves from top to bottom in the Y-axis direction, as shown in Fig. 7. Since the location-based linear schedule expression method allows the user to conveniently identify the corresponding activity in the schedule and the location of the construction work, it was determined that intuitive activity management is possible using this expression method. In particular, the location-based linear schedule is expected to be more useful when applied to projects with expansive workspaces such as linear projects.

6. Conclusions

For efficient activity management of facility construction with activities progressing along the X-axis coordinate in a linear fashion such as roads and railways, the location data of the corresponding activity needs to be shown in addition to the construction time data for each activity. This aspect is differentiated from the activity management of general building construction. In this study, a modeling methodology for linear location-based 4D CAD activity management was proposed. The presented methodology can improve the applicability of the 4D CAD system for civil engineering projects by simultaneously performing the progress simulation according to the schedule of the activity under progress in an expansive construction site and the location data simulation for the activity underway.

Acknowledgements

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BIM and Architectural Heritage

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Abstract

Heritage buildings are crucial in the human perception of culture and identity over time. The sustainable retrofit of these buildings is an opportunity to reuse them taking into account sustainability. HBIM tools (historical building information models) can be used as a comprehensive data collection of information, particularly in the area of building restoration. Based on an international interesting on this kind of studies, the reconstruction process is carried out using BIM software, which shows attention on the software methodology and model structure, and at the same time clarify the added value of a BIM approach, when compared with more traditional CAD modeling systematics. Of particular interest is the approach integrating with more traditional 2D documents and for visualizing reconstruction assumptions within the 3D model representation. BIM focuses mainly on a structured approach to the overall analysis of the architectural object and the organized archival of the reconstruction project. Though virtual reconstruction is not an innovation, this paper explains the methods of preservation of architectural heritage, and the stages of BIM implementation in the digital reconstruction and restoration this kind of buildings and the most important techniques used. Also, explain the application of BIM for modeling and information presentation in different formats. The house of Hamed Saeed in Egypt built by Engineer Hassan Fathi in 1941, is an example. Beside of other examples from different countries worldwide and have just studied by this techniqueClick here and insert your abstract text.

Keywords: BIM; modeling; reconstruction; restoration; software

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1. Introduction

This paper discusses how the technology of building information modeling can be used to preserve Architectural Heritage (AH**).**

Heritage Building Information Modelling (HBIM) is a term that has only begun to be used in the latter part of the last decade. Since Building Information Modelling (BIM) superseded 3D digital modeling and computer-aided design (CAD) as the term which describes the use of information and communication technology (ICT) for the construction, design, and procurement of the modern built environment.

It is sometimes also defined as historical Building Information Modelling, a somewhat narrower term (Murphy et al. 2009).

Building information modeling for historical buildings: is the digital representation of the physical and functional characteristics of historic buildings based on the contemporary state of the historic building. Taking into account all the stages passed by the building including additions, modifications, and restoration work. It is mean some intangible things, such as association, identity, memory and cultural value. "increasing resource scarcities require improved analytical tools for conserving existing buildings in general, and mitigating climate change; and that Heritage buildings

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form a particular challenge, due to the need to conserve their historical and aesthetic worth, addressing environmental social and economic sustainability."[1].

These pillars of sustainability are not fixed; perceptions of quality of life change over time with resulting dissatisfaction with heritage structures and a view that they have become unfit for their purpose [1]. As said the authors of [1] in preparing for the workshop on HBIM in March 2015 in Luxor, Egypt, also claimed that the "Heritage Buildings that are most relevant and at risk were not so much unoccupied national or internationally important monuments, but the cultural backdrop of occupied architecture that: has historic and aesthetic value; demands particular maintenance and refurbishment skills and analysis; deploys expensive materials that may be in increasing shortage; and generally cannot affordably be replaced with better performing new constructions [2].

1.1. Methods of Preservation of Architectural Heritage

Whatever the reason for maintaining the site, conservation should be provided not only to individual units but to the original features of the region as a whole.

Conservation methods vary depending on the type and condition of the impactor architectural heritage and include the following methods:

- REbuild/REproduce

This method involves the reconstruction of old buildings as it was in the past.

- REstore

Restoration of historic buildings and pieces, as in the past.

- REnovate/REinstate

The renewal includes the use of modern materials and attempts to transfer the impact to a condition close to its condition at the time of its construction.

- REvitalization

The process of revitalizing the heritage area as a whole to what it was before, by adding activities and facilities that existed before.

- REctify

To promote the urban, social and economic area in order to improve the level through the addition of activities that were not present before, and consistent with the requirements of the modern era.

- REuse

Includes the use of the building in the same purpose for which it was created or used in a new manner.

1.2. Conservation of the architectural heritage:

It is gradually linked to the periodic maintenance of monuments, thus making preventive maintenance as a real necessity in daily practice. The three-dimensional geometric and structural models have scientific and practical value. They provide support for advanced preventive maintenance programs for architectural heritage and help to maintain over time.

On the other hand, virtual models have great potential for sharing and disseminating knowledge over the Internet and documenting the historic building in all material and non-material contexts. In addition to understanding the historic building and its architectural elements, conducting analyzes and studies about the foundations and infrastructure, and any problems expected in the future and identifying the damaged sites in the historical building and follow-up during his life cycle.

More importantly, give a comprehensive overview for decision-makers with the participation of this model with them, which helps to make the right decision towards these buildings.

It is also possible to take advantage of the historical buildings information modeling in the creation of a specialized architectural library that includes all the details and architectural elements of historic buildings, and also can be used in modern projects, which helps to preserve the authenticity of these elements and their golden proportions.

1.3. Management and maintenance of cultural heritage buildings

The tasks related to the management and maintenance of cultural heritage buildings urgently need comprehensive information on the complete characteristics of the building to carry out. To facilitate this; a large amount of data should be collected from various sources and in various file formats. Then an integrated information system can be created that covers all the physical and functional characteristics of the building. Indeed, the required data can be very heterogeneous. That mean the documents, plans, historical maps and graphical texts, as well as the latest data from historical structural investigations and geodetic surveys?? Geodetic surveys or photographic survey. Given that all architectural heritage objects are inherently 3D spatial properties, the resulting information system, which will include all of the above documents, should allow the management of 3D models. Even this may not be enough because we often need to represent a 4D historical building to describe its changes throughout time.

The disciplines that intersect with the use of building information modeling in many historic buildings include architecture, civil engineering, materials chemistry, sustainability, history, and heritage, as well as the specialization of geomatics and Photogrammetry. These disciplines contribute directly and indirectly to enriching the modeling of historical building information modeling in many aspects, including the identification of used materials and the old methods of building and methods of restoration and maintenance of these buildings.

The current development of new and more effective digital technologies, such as building information modeling, 3D modeling, laser scanning techniques, animation, and simulation, has opened new scenarios for reading and interpreting architectural heritage and facilitating the movement of its designs. This is particularly useful in maintenance and restoration.

Now it is possible to build models of existing buildings, demolished buildings or buildings that were not originally built, not only as the original or as built, or some intermediate stages, but also by taking into consideration the design intentions, the building constraints, and variables. By adding the fourth dimension of the historical building model. Depending on the modeling of construction information, architectural details or structural elements often show periods of construction of the historic building and any increases or modifications to the building. For example, there are temples and ancient houses that were not built at once, but in different stages and periods of time. For example, the house of Hamed Saeed in Marj and built by Engineer Hassan Fathi, the house was built in two phases in 1941, the main interior unit was built, consisting of a central chamber covered by a dome and connected to a vaulted Iwan. It refers to the hall, i.e., the typical main room of the historic houses of Cairo, and there is an exterior, large arched Iwan (Arcade) was built near the room and overlooks the rural nature. In the second phase of 1945, he designed additional rooms around the tree-lined courtyard: the number of two main rooms on each side, and two double rooms (each unit consisted of a room covered with a dome connected to a smaller unit), all connected to a covered arcade on the other side. And the rooms are covered with a dome, except for the two (Iwans) and the Riwaq (Arcade) covered with the arches.

For historical buildings such as the Luxor Temple and other historical buildings, the use of building modeling is not difficult, but the difficulty lies in knowing what is behind the walls. For example, in many historical buildings, specialists study parts of the walls to know the structure and physical properties of the walls. Many times, some structural elements are invisible, which may lead to the use of the wrong method or structural element by the specialist. In this case, you should use more advanced means such as XRF and others, to build a valid model and get the required analyzes and studies correctly.

1.4. Stages of Application of Building Information Modelling in Historical Buildings:

Building information modeling in historical buildings is applied in three phases:

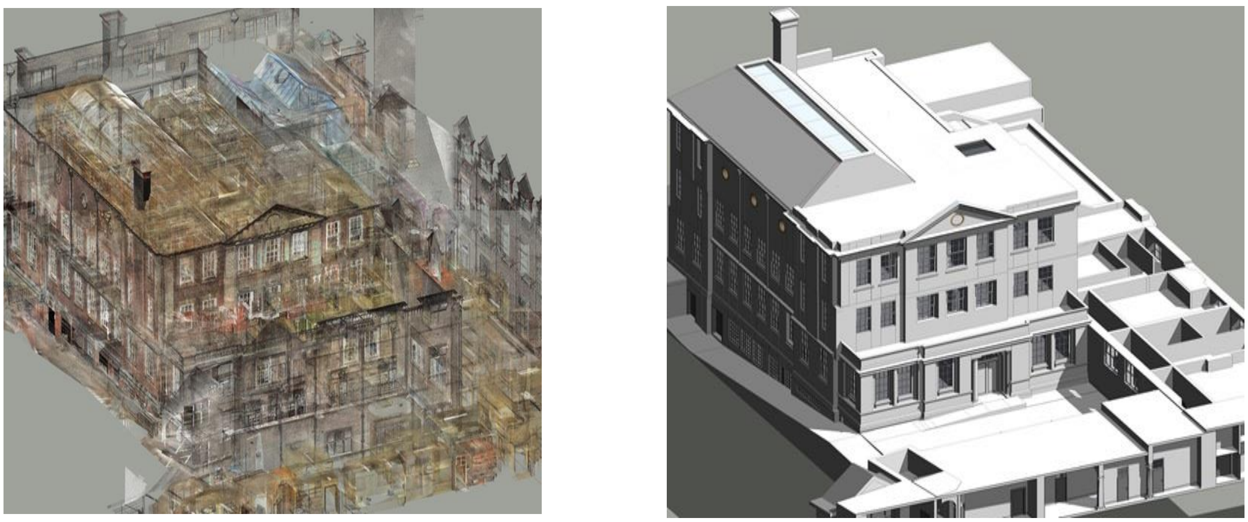
- The first stage is the collection of data from the site and always uses laser scanning technology and photogrammetry to collect the most detail, accuracy and in high quality.
- The second stage is the phase of data processing.
- The third stage is the building of the model divided into categories such as floors, walls, and doors.

Based on the available information from the laser scanner and the architectural survey, the model is divided into "work sets" with building elements such as walls, doors, floors, stairs, and pipes. All other team members can view these items but they are not able to change them, and any information available on the site is added as construction site and architectural plans, reports, and works of restoration and maintenance, method of construction, historical documents, the differentiation of structures according to the stages of construction and other information.

The definition of a 3D laser scanner is a tool that analyzes structural elements or an urban environment for the collection of spatial and physical information related to its shape and appearance, followed by the process of using the collected information for the purpose of constructing a three-dimensional digital model as a copy of the original used in a wide range of applications. The formation of a cloud of points for the geometrical coordinates of the elements of the surfaces of the documented form through the pulse or continuous projection of a laser ray is the main and typical stage in this technique, through which digital models are formed for the original element. The colors of the finishing materials of the documented elements can be scanned and digitally created when using the feature of (Clear Color Info) for each point during the scanning process.

Photogrammetry is a science and technology specialized in acquiring information about elements and the physical environment through the process of recording, measuring and interpreting photographs. It is one of the formulas that rely on the use of a camera which can be adjusted or metric camera instead of other scanning tools. This camera has a lens that can be changed and controlled. This means that the lens is accurately measured and that the focal length of the camera is known. It also has a special plate attached to the film to save its negative surface when taking pictures. This plate projects small intersections in the form of (+) on the output, any distortion that appears on the image will be determined at the exit process.

Photogrammetry is a standard technique that identifies the three coordinates (x, y, and z) of the component points of the element through measurements that can be obtained from two or more photographs of the building or scene taken from different locations. Commonly used to interpret the elements: what is it? What sort? What is its quality and/or quantity? Also used to measure elements: Where are they? What is its structure or size?



D Scanned Image of Educational Centre, London, UK BIM Model of Educational Centre, London. [3]
Fig.1. (Creating intelligent 3D BIM workflows and information-rich models from laser surveyed data images and the point could capture by drones.)

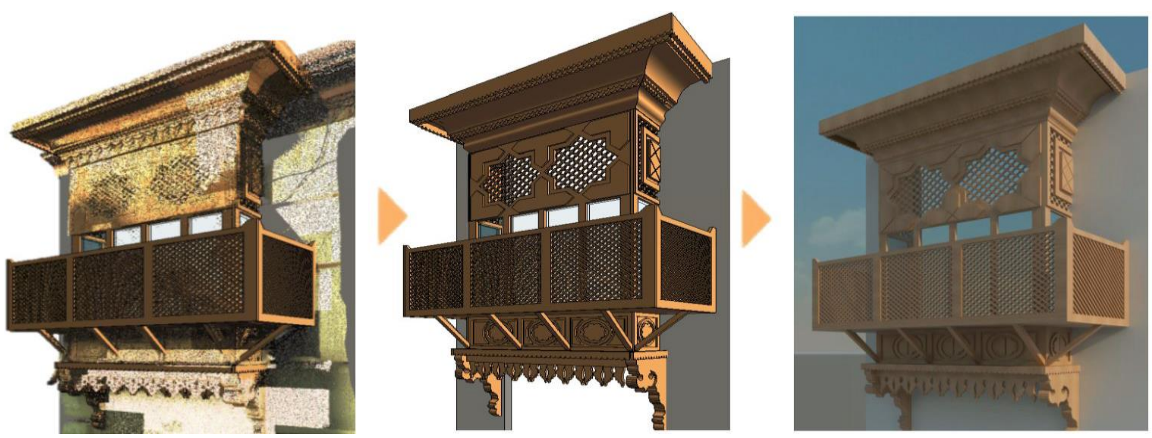


Fig.2. Creation and visualization of a 3D model based on a point cloud. Source (Jeddah Historical Building Information Modelling "JHBIM" – Object Library)

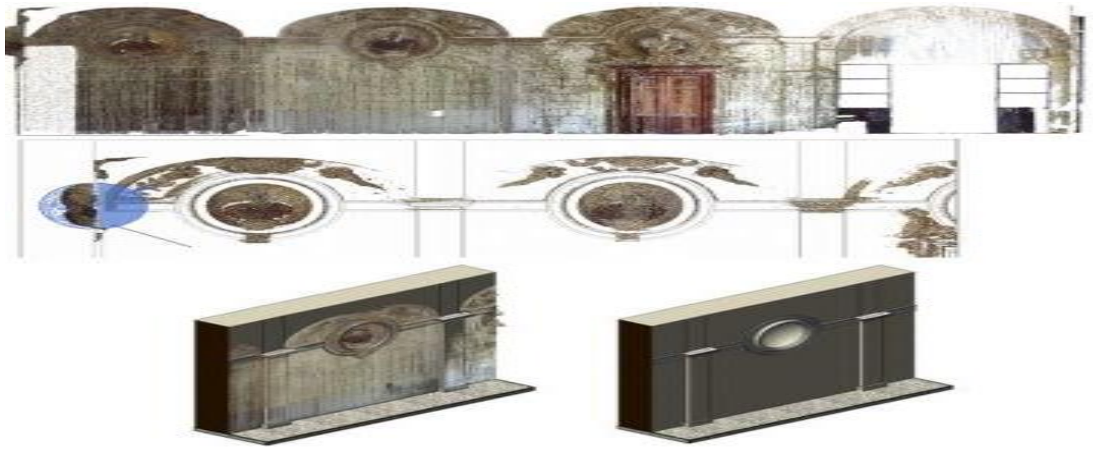


Fig. 3. Valentino Castle. The architectural elements were divided into groups with different levels of shape recognition difficulties and were treated accordingly. Source: BIM Methodology as an Integrated Approach to Heritage Conservation Management.

The techniques used to transform the building into a three-dimensional model are many, but even today there is no technique to transform the historic building or buildings directly into a complete model in a fully automatic manner. The advanced techniques used in many historical sites in Europe are laser surveying and architectural surveying. They are then modeled using the automatic method of predefined parts such as drainage, air conditioning, and electricity; while the more complex parts are often modeled according to specialists.

The degree of detail varies according to the objective of using the building information model for historic buildings. Here, one must distinguish between the use of building information modeling and the use of advanced scanning methods such as laser scanning. For the laser scanner, the output is the outer shell of the walls and the elements to be scanned. For example, if we want to make a laser survey of a historical building in the outputs, the outer shell of the building will be inside and outside. In this case, we can produce a three-dimensional model, horizontal projections, and facades, and this information may be used in the presentation, virtual reality, quantities, specifications of materials and others. The role of building information modeling for historic buildings is to transform the laser survey outputs into a complete model that contains the quantities and specifications of the physical building, the properties of the materials used and other known uses of building information modeling. See figures 2, 3.

1.5. Obstacles to the use of building modeling for historic building:

It can be divided into the following:

- Difficulties in historical sites, which are complicated in several aspects: geographical complexities in the site or geometric complexity in the form of the building in terms of design, etc., complexities in obtaining permission from the responsible authority or the owner of the site, in addition to the danger of some sites and historic buildings, especially those threatened by failures.
- Technical difficulties in the absence of an architectural library of such historical buildings and architectural elements, while the architectural library of modern buildings is very rich in architectural details or as called (blocks). For example, if you look at any building information modeling software for a particular door or window, you may find many shapes and designs that you may find from the manufacturer and all you need to add or include in the model. On the other side, a historical architectural element such as Mashrabiya (Rushan) is very difficult to find but must be rebuilt from the beginning to fit the historic building. This is in addition to the lack of most of the architectural materials used in such buildings, for example, the special stone, and the provision of “blocks” for temporary equipment of construction used during the construction of the archaeological building.
- Physical problems and obstacles arise in the high costs of using technologies such as laser scanner, in addition to the high costs of modeling historical buildings and the lack of specialists in this field at the national and international levels.

- The volume and quantity of data produced from it that may pose challenges and difficulties in processing and transfer. To solve this problem; there are several simplest ways to set up the site and make a good laser scanning plan so that the desired target is selected and the clear angle is chosen so that the minimum number of points of laser scanning is done, taking into consideration the accuracy required for the laser scanner.

One of the advantages of using building modeling in historic buildings is to dispense of Point Cloud files after completing the modeling in a manner that may lead to total dispensing and rely on the building information model in analyzes, studies, presentation, etc.

1.6. The most prominent Arab/ international organizations that used building information modeling in historical buildings

After the support of British government to the idea of using building information modeling for modern projects that cost more than 5 million £, attention has been drawn to the potential benefits of using this technology in existing buildings, projects and historic buildings. One of the organizations supporting this trend is English heritage. Unfortunately, there are few of prominent projects that benefited from information modeling technology for historic buildings, including , as mentioned above, the Sagrada Familia Cathedral in Spain, the castle of Mascara in Italy, Lerico in Milan, the study of the towers of Milan Cathedral, and the historic building of the Naseef House in Jeddah.

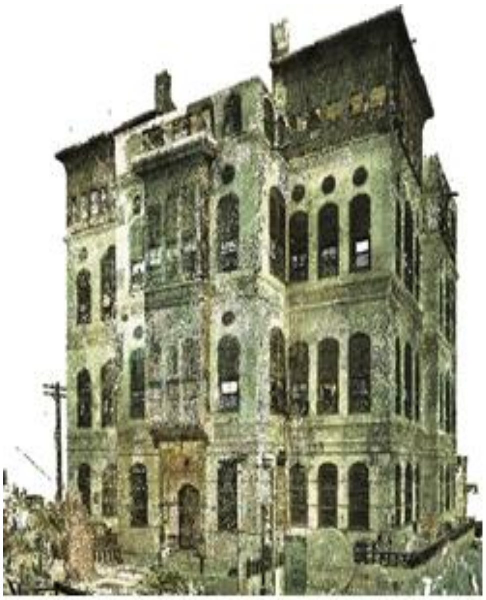


Fig.4. On the left side is a house of Nassif, a product with a laser scanner, and on the right side is a building information model for the historic house of Nassif in Jeddah, Saudi Arabia JHBIM. [4]

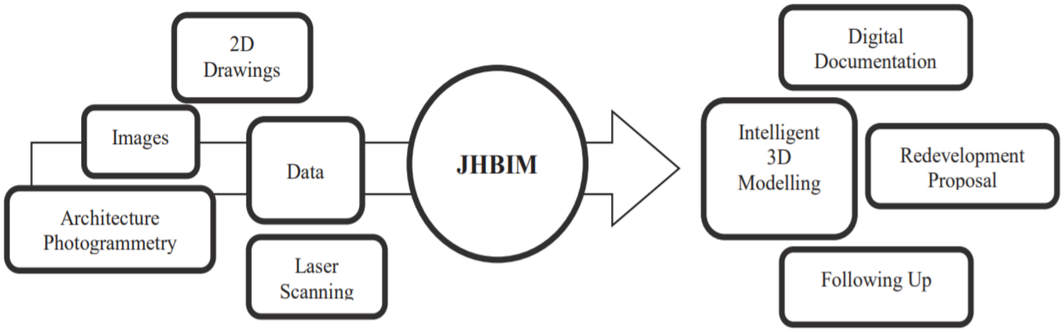


Fig.5. JHBIM Approach from Baik et al [4]

An initiative called Jeddah Historical Building Information Modeling (JHBIM) deals with the archaeological buildings in Jeddah and aims to introduce BIM tools to document the historical buildings in Jeddah. Traditional survey methods are being used to create data on existing buildings. These tools have high costs, often consume a lot of time and will help the importance of such a database in determining their circumstances and making decisions regarding the management, reuse, and maintenance of these buildings.

You can take advantage of the experience of countries such as Italy, the UK, Canada and Spain. One of the most famous historical projects in which building information modeling was used was the Sagrada Familia Cathedral by architect Anthony Gaudi, whose work began in 1882 until now. The technique of building information modeling has helped to build many complex elements of the building that are difficult to construct at the time [5].

Sagrada Familia Model Manchester Town Hall Complex. Source: (Manchester Central Library)
Fig. 6. The most important historical projects for which building information modeling was used

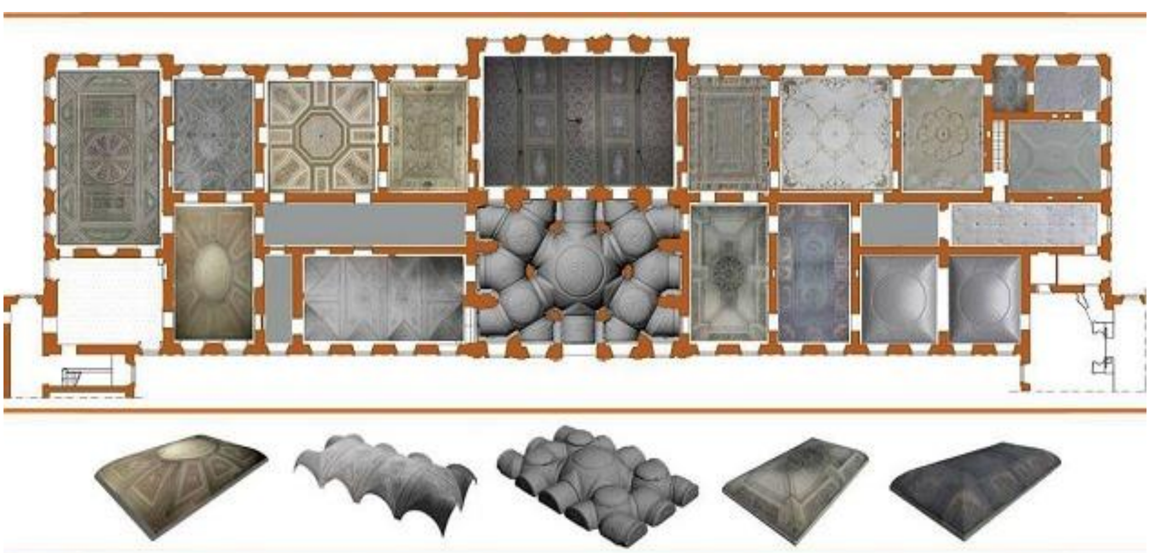


Fig.7. Results of multiple surveys of the Villa Reali di Monza building in Italy using laser scanner as part of the policy of preservation and management of building information. *Source: (Historic Building Information Modeling - HBIM) Dr. Emad Hani Al-Alaf*

1.7. The most important PIM programs used in the work of architectural heritage model can be divided into:

1- Software convert cloud points from the laser scanner to model elements such as Autodesk ReCap

2- Programs for model creating such as Edificius Free UPP & Revit & ArchiCAD & TeklaStructures
3- Software for cities such as Autodesk InfraWorks 360
4- View of the model such as Tekla BIMSight & xBIMXplorer
5- Analysis such as Green Building Studio
6- Software for adding a fourth dimension such as NavisWorks
7- Facility and facility management software such as ArchiBUS or GraphisoftArchiFM. [6].

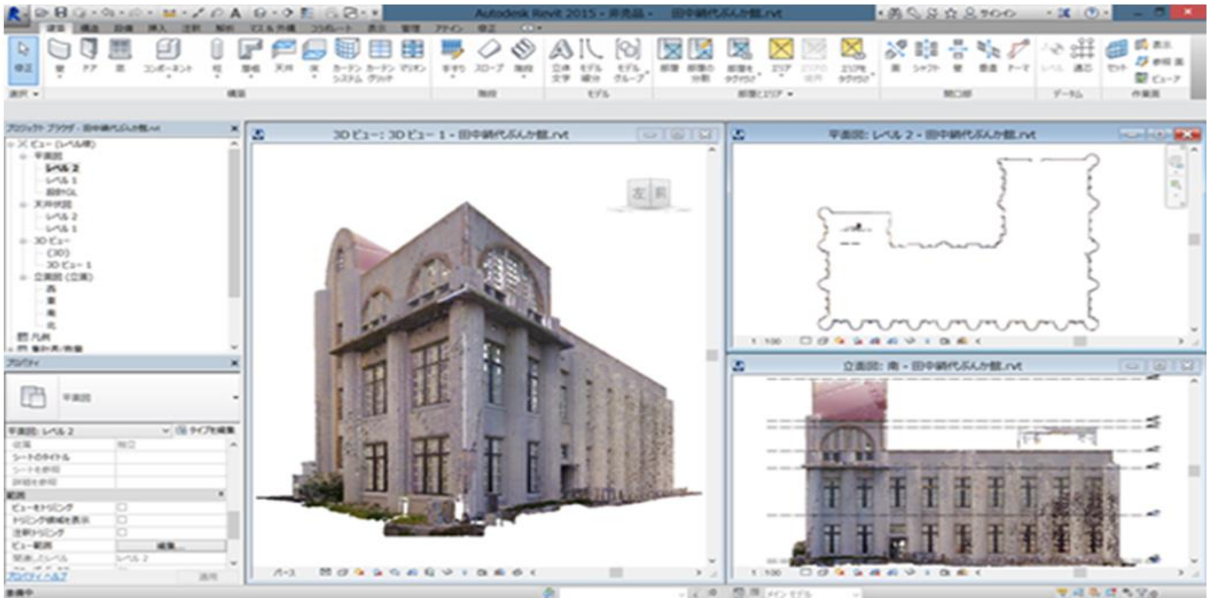


Fig.8. The first three-dimensional digital model in Japan for a registered historic building to help to preserve the museum. Source [7]

2. CONCLUSION

We recommend doing a building information model for all buildings to preserve and maintain them and provide digital copies to those who admire buildings around the world

Acknowledgments

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BIM training in construction management educational practices in Croatia and Slovakia

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Abstract

Building Information Modeling (BIM) is an intelligent 3D model-based process that enhances productivity and management performance of construction projects. For its successful adaptation, education and standardization are one of the prerequisites and key success factors. Even though some countries in the European Union have started to mandate the usage of BIM on all public projects and have developed standards to support such implementation, Croatia and Slovakia have done little to support such initiatives. Furthermore, to support BIM usage, universities need to update their curricula accordingly and thus enable construction engineers the knowledge and skills. This would lead to new BIM competencies. In order to understand the current status quo of the BIM education provided in Croatia and Slovakia, map the reasons of scarce BIM initiatives and propose guidelines for improvements, we surveyed and compared two representative civil engineering faculties which are Faculty of Civil Engineering Košice and Faculty of Civil Engineering Zagreb. The survey investigated Construction Management program on master study and assessed achievement of each BIM learning outcomes. The results show that very little has been done in integration of different knowledge areas towards open BIM approach. This is especially evident in the knowledge areas such as coordination, interoperability and clash detection. Hence, some rare courses which include BIM are being taught independently of each other and could be set to BIM level 1 maturity level. At the end of the paper we provide guidelines for improvement of undergraduate and graduate studies.

Keywords: building information modeling; construction management; Croatia; education; Slovakia.

1. Introduction

Building Information Modeling (BIM) is an intelligent 3D model-based process that enhances productivity and management performance of construction projects. Implementation of BIM is steadily gaining popularity in construction industry and as such BIM knowledge represents important learning outcome in higher students' education. Moreover, to increase the BIM application, authors suggested several strategies where providing BIM education at university level is one of them [1]. Even though BIM shows promising results and is the current trend in the construction industry, and many countries are obliged to use it, education of construction engineers (pedagogy, curricula, learning outcomes etc.) still has not caught up with the trends [2]. Reasons for absence of BIM in the curricula of civil engineering practices can be found in inadequate and not educated staff, inadequate resources and support to make the curriculum changes and the fact that there is no space left within curriculum [3, 4, 5, 6, 7, 8]. As a result, the industry suffers from insufficient educated employees [9]. Furthermore, BIM education at universities is often directed to software training which is not enough for deeper understanding of BIM concept and development of BIM skills [4, 10]. Besides, researchers [4, 5, 7] recommended to create a plan for BIM integration into Architects, Engineering and Construction (AEC) curricula and to define basic BIM knowledge areas important for future civil engineers. These

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actions will help in creating awareness for BIM implementation in higher education [5, 6, 11]. Introducing of BIM in education should start as soon as possible, so it is recommended within undergraduate study. Current and better technologies should be presented to students before they start to learn old and not so useful technology. Thus, vertical integration of BIM education is very important for spreading complexity of problems so BIM education should be part of undergraduate, graduate and postgraduate study [5, 6]. This trend will increase the percentage of BIM usage among students as well as practitioners [5, 6].

Problem connected with BIM education within Construction Management (CM) field is to define learning outcomes, curriculum of courses and specific knowledge which is necessary for future construction and project managers. Sacks and Pikas classified BIM competency topics which are necessary to realize through the first or master degree level of CM program in three categories: BIM-related general knowledge area and processes (12 topics), BIM technology (10 topics) and BIM applications/ functionalities (17 topics) [12, 13]. Moreover, CM education should start with the first phase of creating a new model. If students did not complete 3D model, they would not develop needed skills of spatial visualization which is very important to understand how processes of material procurement, cost estimation and scheduling work together, but also how to accomplish their integration [14, 15]. Additionally, Kim found the following objectives of CM education: evolve student's skills, ability and construction knowledge to develop appropriate levels of cost estimates; evolve communication skills and ability to function in multidisciplinary teams [16]. Nevertheless, processes of comparing the architectural, structural and services models, for coordination and clash detection, is proven to be a necessary step in understanding collaboration and interoperability [14, 15, 17]. In majority higher educational programs integration and collaboration between disciplines have not been achieved yet. Therefore, BIM education is often part of separated departments and disciplines with minimal trust between project participants [5, 18] and in such environment is hardly to expect encouraging information integrity and collaboration. Thus, horizontal integration of BIM education is necessary [6]. Besides, BIM learning outcomes could be reached thought single-course (when BIM is introduced only to one discipline), interdisciplinary collaboration (when students are learning BIM concepts through two or more disciplines within one university), distance collaboration (when students learn real BIM collaboration with students from two or more distance universities and driplines), BIM capstone courses or project and multinational academic experience [10, 19].

Larger companies with more employees find BIM in constructability and visualization to contribute the most to the success of their projects. Thus, these companies need employees with two conceptual roles Design-Build and Construction Managers with BIM knowledge [20] to enable latest project delivery [21]. Furthermore, Uhm et al. identified eight BIM job types which included BIM project manager, director, BIM manager, BIM coordinator, BIM designer, senior architect, BIM MEP coordinator and BIM technician but also identified BIM competencies for each BIM job group [22]. They classified BIM competencies into groups which are essential (required for all BIM job groups), common (required for a majority of job groups) and job-specific competencies (required by some BIM job groups) [22]. Research by Uhm et al. provides roadmap for becoming an expert in each role as well as it could be good start point when defining BIM education and training for students in higher education and employees in construction companies [22]. Moreover, BIM professions BIM manager/engineer and BIM project manager are the most common professions connected with BIM. According to Wang and Leite BIM manager/engineer is required to understand what BIM is and how it changes the work process, have abilities to create BIM models, to perform data analysis with existing BIM models, to use BIM visualization and communication tools but also have experience in working with specific BIM tools. In comparison with BIM manager, BIM project manager may or may not directly use BIM, but has to understand what BIM is and how it changes the work processes, should have abilities to use BIM as a visualization and communication tolls but also to perform data analysis whit existing BIM models [2]. Rahman et al. identified BIM skills which are 'BIM', 'Revit', 'CAD', '3D', 'steel detailing', 'Navisworks', 'submittals', 'modeling', 'construction drawings', 'AutoCAD', 'sustainable design', 'metal fabrication', 'renovation' and 'steel' [23]. Accordingly, specific BIM jobs and BIM skills are often defined by observing BIM trends and practices in the construction industry, industry perceptions, job advertisement, interviews with BIM experts, etc. Therefore, AEC programs need to integrate BIM education within their curricula to ensure adequate education for future civil engineers and prepare them for their future career in real construction sector. Thus, both academia and industry need to focus on BIM education and cooperate in BIM issues to maximize benefits from BIM usage [10].

According to previous study [24] BIM education in the field of construction management at Technical University of Košice, Faculty of Civil Engineering is not fully extended to the Master´s level (2nd level of education). There are some courses with BIM education, but not in the construction management field. Students have good opportunity to get acquainted with BIM but acquired knowledge is more theoretical than a practical one. Likewise, the academic experience which is reached through BIM education at University of Zagreb, Faculty of Civil Engineering is a single course collaboration because BIM is introduced only through one discipline within university [25]. From the above is evident that specific data about learning outcomes and necessary knowledge areas connected with BIM education in

CM field currently does not exist. Additionally, deeper analyses of implemented BIM education and BIM courses is necessary to define the way of their extension [19]. So, the aim of this paper is to compare and discuss educational approaches in BIM education of civil engineers (specifically at the Faculty of Civil Engineering Košice and Faculty of Civil Engineering Zagreb) in order to define guidelines for the further development of BIM education on mentioned faculties.

First, this paper presents methodology of the research and then it gives the results of research conducted at the Faculty of Civil Engineering Košice and the Faculty of Civil Engineering Zagreb. The paper brings discussions by comparing the results with similar education studies (master study, CM program). In the end, the paper gives conclusion and proposes how to improve BIM education practices on both faculties.

2. Methodology

In this study we surveyed the students after they finished their BIM education on their level of study (master study in Construction Management field). They were asked whether they have acquired the required skills in working with BIM tools but also the basic knowledge about the BIM concept. Moreover, we will use student's perception of current BIM training to asses and analyze current educational practices in construction management area in Croatia and Slovakia. All the students who participated in survey (86 students) have been on the first or second year of graduate study, Construction Management study program. 34,89% (53,3% on first year; 46,7% on second year) of them study at the Faculty of Civil Engineering Košice while 65,11% (57,1% on first year; 42,9% on second year) of participants study at the Faculty of Civil Engineering Zagreb.

The survey consisted of 4 types of questions. The first two types were closed type of questions (yes / no and closed select options). In the third type, the respondents had to rate answers using the Likert scale 1-4 (given scale; 1-minimum value of the offered answers; 4-highest value to an answer). The comparative analysis of the two university groups was based on the Relative Importance Index (RII), according to the formula (1):

$$RII = \frac{\sum w}{A \times N} \quad (1)$$

where w represents the assessment or response of the individual participant of the survey, A, the highest score given by the survey participants while N is the total number of respondents who participated in the study [26]. RII refers to a value in the range from 0 to 1. The higher value of the index RII means that element is more important or has better perception [27, 28]. In fourth type of questions we gave students list of BIM competencies connected with BIM processes, BIM technology and BIM applications and they should rate their level of knowledge (theoretical, practical or both) acquired thought their BIM education. One of the option was that listed BIM competency was not included in their BIM education. When doing list of BIM competencies we used identified specific BIM competency topics by Sacks and Pikas which are necessary to realize through the first or master degree level of CM study [12]. We added 'Cost management' as additional BIM competency in categories BIM processes and BIM technology.

3. Results

According to previous studies [24] at the Faculty of Civil Engineering Košice BIM education has been part of undergraduate and graduate study while at the Faculty of Civil Engineering Zagreb the students had never heard about BIM before entering the graduate level of study [24, 25, 27, 28, 29]. After BIM education at their faculties most students could define BIM (Košice 90%, Zagreb 100%, Table 1). Table 1 shows how application of BIM brought progress in education and increased student's understanding of the construction management (Košice 100%, Zagreb 98,21%, Table 1), and consequently allowed progress in education and understanding of the construction management discipline (Košice 83,33%, Zagreb 98,21%, Table 1). Likewise, respondents from Košice thought that past CAD and Microsoft tools (CAD and Microsoft tools) are sufficient (73,33%, Table 1) for realistic planning and for complex projects which today's construction industry is exposed to, while the respondents from Zagreb thought completely different (8,93%, Table 1). Moreover, most of the students thought that integration of technical specification with costs and time plans (Košice 96,67, Zagreb 96,43%, Table 1), as well as communication between stakeholders who are involved in construction projects, are the areas which are completely missing (Košice 96,67, Zagreb 100%, Figure 1). Further, most respondents wanted to use BIM in their future practice (Košice 80%, Zagreb 100%, Table 1).

Table 1. Comparison of students' answers on specific YES/NO questions

QUESTION	KOŠICE YES	KOŠICE NO	ZEGREB YES	ZEGREB NO
Can you define Building Information Modeling (BIM)?	90,00%	10,00%	100,00%	0,00%
In your opinion application of software tools that are currently available on the market can improve construction management processes.	100,00%	0,00%	98,21%	1,79%
In your opinion application of BIM technology allows progress in education and understanding of the construction management discipline.	83,33%	16,67%	98,21%	1,79%
In your opinion CAD and Microsoft tools (Word, Excel, Microsoft Project) are sufficient for proper and realistic planning.	73,33%	26,67%	8,93%	91,07%
In your opinion construction industry requires the integration of technical specification with costs and time.	96,67%	3,33%	96,43%	3,57%
In your opinion in the construction industry there is a need for better communication of different professions during the project design and execution.	96,67%	3,33%	100,00%	0,00%
Would you like to use BIM in the near future practice?	80,00%	20,00%	100,00%	0,00%
In your opinion software tools, which are currently promoted as BIM applications, can mutually exchange information, different formats, standards (e.g. Vico and Navisworks or ArchiCAD and Revit).	83,33%	16,67%	76,79%	23,21%

The results also showed that respondents saw construction companies in their country very inefficient with BIM usage 0-25% (Košice 77%, Zagreb 100%, Figure 1, left) but they also think that percentage of BIM usage in the world is pretty higher 50-75% (Košice 54%, Zagreb 68%, Figure 1, right).

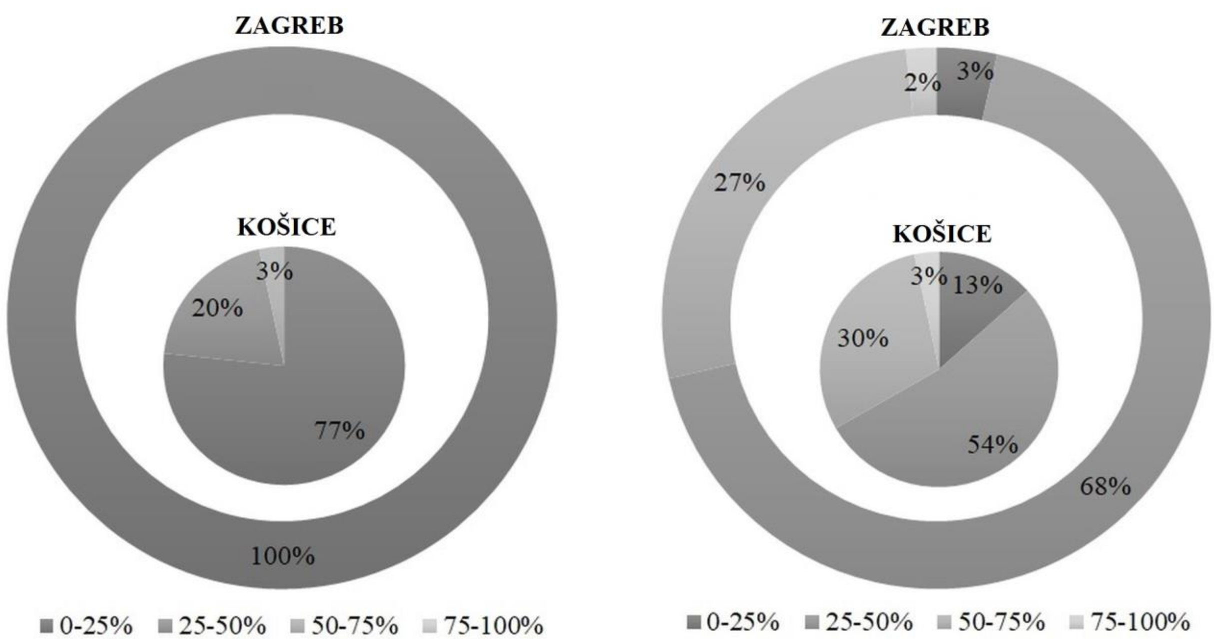

Fig. 1. Comparison of students' answers on question: 'In which percentage do you think that BIM technology is applied in your country (left figure) / in the world (right figure)?'

Additionally, the BIM software which were used in education (Košice 83,33%, Zagreb 76,79%, Table 1) were generally compatible with one to another. At the Faculty of Civil Engineering Košice best rated software were iTWO 4.0 (0,86, Figure 2), BIM Estimate (0,83) and Nemetschek Nevaris (0,83) while at the Faculty of Civil Engineering Zagreb best performance had Nemetschek Allplan (0,89, Figure 2), GALA Construction Software (0,79, Figure 2) and Autodesk Navisworks (0,72, Figure 2). We should highlight here that at the Faculty of Civil Engineering Košice more than 75% of participants have never used Cubit Buildsoft, Exactal COST X, GALA Construction Software, iTWO 4.0. and Synchro PRO while at the Faculty of Civil Engineering Zagreb more than 90% of survey participant have never used software, Cenkros, Cubit Buildsoft, Exactal COST X, INNOVAYA Visual Estimate, iTWO 4.0, Kalkulus, RSV and Synchro PRO.

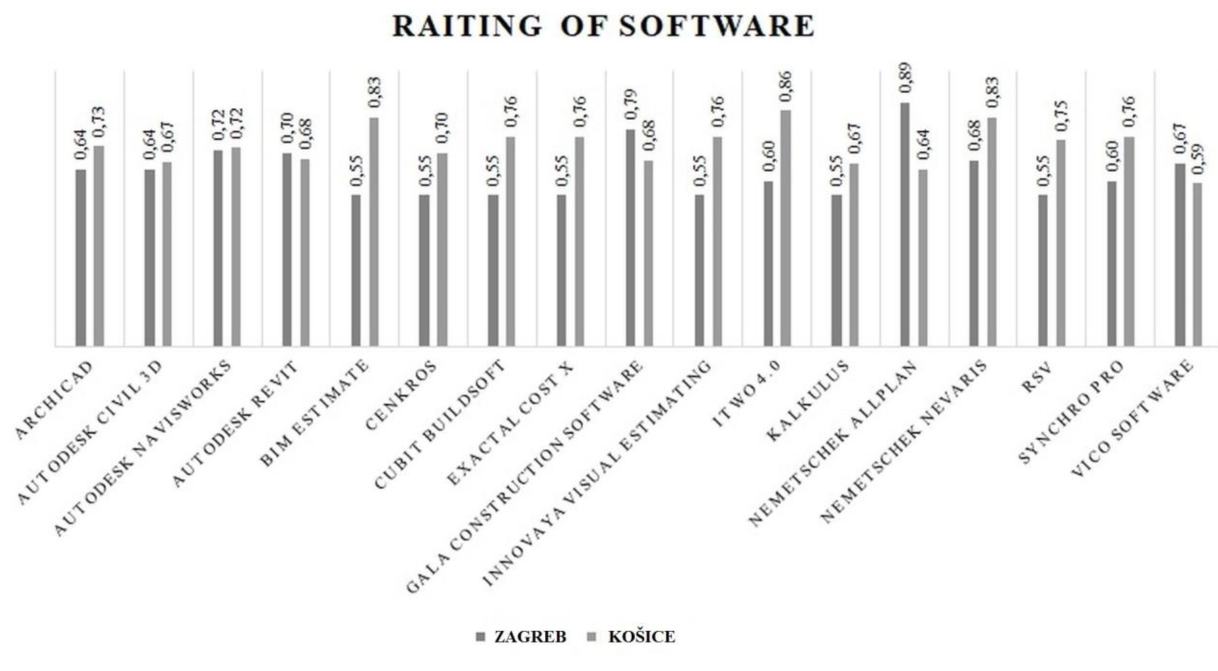

Fig. 2. Comparison of software rating

Besides, results (Table 2) show that students at master's level of study at both universities in general acquired theoretical knowledge connected with BIM processes while only 'Cost Management' is included in theoretical and practical knowledge at the Faculty of Civil Engineering Zagreb (51,79 %, Table 2). Moreover, BIM competencies 'Data security' (46,67%, Table 1) and 'Design coordination' (36,67%, Table 1) were missing in BIM education at the Faculty of Civil Engineering Košice while 'Data security' (48,21 %, Table 1), 'Constructability review and analysis' (41,07%, Table 1) and 'Contractual and legal aspects of BIM implementation' (58,93%, Table 1) were missing in BIM education at the Faculty of Civil Engineering Zagreb. It can be concluded due to higher percentage of respondents who thought that this BIM competencies were not included in BIM education.

Table 2. Students' rate of the competency acquired by learning the following BIM processes throughout their education

BIM PROCESSES	KOŠICE				ZAGREB			
	T	P	T&P	NO	T	P	T&P	NO
Overall construction design management and contracting procedures	**60,00%**	0,00%	20,00%	20,00%	**67,86%**	1,79%	21,43%	8,93%
Facility maintenance and management	**46,67%**	10,00%	10,00%	33,33%	**66,07%**	0,00%	10,71%	23,21%
Advantages and disadvantages of BIM for design and construction processes	**40,00%**	0,00%	33,33%	26,67%	**57,14%**	3,57%	35,71%	3,57%
Model-progression specification and level-of-detail concepts	**46,67%**	6,67%	20,00%	26,67%	**57,14%**	1,79%	3,57%	37,50%
Changes in management procedures	**63,33%**	6,67%	6,67%	23,33%	**53,57%**	0,00%	8,93%	37,50%
Data security	36,67%	3,33%	13,33%	**46,67%**	41,07%	0,00%	10,71%	**48,21%**
Information integrity	**50,00%**	3,33%	13,33%	33,33%	**50,00%**	1,79%	17,86%	30,36%
Design coordination	30,00%	3,33%	30,00%	**36,67%**	**55,36%**	1,79%	19,64%	23,21%
Constructability review and analysis	**50,00%**	0,00%	16,67%	33,33%	33,93%	1,79%	23,21%	**41,07%**
Management of information flows	**46,67%**	3,33%	13,33%	36,67%	**44,64%**	1,79%	10,71%	42,86%
Contractual and legal aspects of BIM implementation	**53,33%**	3,33%	6,67%	36,67%	39,29%	1,79%	0,00%	**58,93%**
BIM standardization (in organizations and projects)	**63,33%**	0,00%	10,00%	26,67%	**67,86%**	1,79%	10,71%	19,64%
Cost management	**46,67%**	3,33%	20,00%	30,00%	37,50%	3,57%	**51,79%**	7,14%

Furthermore, Table 3 shows that students at the Faculty of Civil Engineering Košice only acquired theoretical knowledge about 'Basic BIM operating skills' (53,33%, Table 3) and 'Laser scanning' (40,00%, Table 3) while other competencies connected with BIM technology were not included in BIM education. Students at the Faculty of Civil Engineering Zagreb acquired: only theoretical knowledge connected with ‘Communication tools, media, channels and feedback’ (42,86%, Table 3), ‘Ways to store and share information (e.g., cloud computing, networking, big-room equipment)’ (41,07%, Table 3) and ‘Choosing right BIM technologies/ processes/tools for specific purposes’ (50,00%, Table 3); theoretical and practical knowledge about ‘Basic BIM operating skill (80,36%, Table 3), ‘Modeling with standard catalog elements’ (60,71%, Table 3), ‘Creating and modeling with custom elements’ (50,00%, Table 3) ‘Interoperability (file formats, standards, and structure for data sharing)’ (64,29%, Table 3) and ‘Cost management’ (44,64%, Table 3) while ‘Massing/solid modeling’ (66,07%, Table 3), ‘Central databases/information repositories’ (33, 93%, Table 3) and ‘Laser scanning’ (91,07%, Table 3) were missing in BIM education.

Table 3. Students’ rate of the competency acquired by learning the following BIM technology throughout their education

BIM TECNOLOGY	KOŠICE				ZAGREB			
	T	P	T&P	NO	T	P	T&P	NO
Basic BIM operating skills	**53,33%**	13,33%	13,33%	20,00%	14,29%	1,79%	**80,36%**	3,57%
Modeling with standard catalog elements	20,00%	13,33%	23,33%	**43,33%**	12,50%	3,57%	**60,71%**	23,21%
Creating and modeling with custom elements	30,00%	10,00%	23,33%	**36,67%**	10,71%	5,36%	**50,00%**	33,93%
Massing/solid modeling	36,67%	10,00%	13,33%	**40,00%**	16,07%	3,57%	14,29%	**66,07%**
Central databases/information repositories	36,67%	6,67%	16,67%	**40,00%**	28,57%	5,36%	32,14%	**33,93%**
Interoperability (file formats, standards, and structure for data sharing)	20,00%	10,00%	30,00%	**40,00%**	28,57%	1,79%	**64,29%**	5,36%
Communication tools, media, channels and feedback	16,67%	20,00%	13,33%	**50,00%**	**42,86%**	3,57%	16,07%	37,50%
Ways to store and share information (e.g., cloud computing, networking, big-room equipment)	26,67%	13,33%	16,67%	**43,33%**	**41,07%**	3,57%	25,00%	30,36%
Choosing right BIM technologies/processes/tools for specific purposes	20,00%	10,00%	13,33%	**56,67%**	**50,00%**	7,14%	17,86%	25,00%
Laser scanning	**40,00%**	10,00%	23,33%	26,67%	5,36%	0,00%	3,57%	**91,07%**
Cost management	33,33%	13,33%	16,67%	**36,67%**	33,93%	5,36%	**44,64%**	16,07%

Moreover, results in Table 4 show that students at the Faculty of Civil Engineering Košice acquired theoretical knowledge about ‘Perform structural analysis’ (36,67 %, Table 4) and ‘Rapidly generate and evaluate construction plan alternatives’ (43,33 %, Table 4) while students at the Faculty of Civil Engineering Zagreb acquired theoretical and practical knowledge about ‘Create renderings and representations for aesthetic evaluation’ (55,36%, Table 4), ‘Perform automated quantity takeoff and cost estimation’ (73,21%, Table 4), ‘Perform automated generation of drawings and documents’ (39,29%, Table 4), ‘Perform 4D visualization of construction schedules’ (58,93%, Table 4) and ‘Monitor and visualize process status’ (42,86%, Table 4). Other competencies connected with BIM applications were not included in BIM education at any faculty.

Table 4. Students’ rate of the competency acquired by learning the following BIM applications throughout their education

BIM APPLICATIONS	KOŠICE				ZAGREB			
	T	P	T&P	NO	T	P	T&P	NO
Create renderings and representations for aesthetic evaluation	30,00%	6,67%	16,67%	**46,67%**	5,36%	5,36%	**55,36%**	33,93%
Rapidly generate multiple design alternatives	33,33%	13,33%	16,67%	**36,67%**	23,21%	3,57%	23,21%	**50,00%**
Perform energy analysis	26,67%	6,67%	10,00%	**56,67%**	7,14%	0,00%	1,79%	**91,07%**
Perform structural analysis	**36,67%**	13,33%	13,33%	**36,67%**	7,14%	0,00%	7,14%	**85,71%**
Perform automated quantity takeoff and cost estimation	33,33%	3,33%	16,67%	**46,67%**	12,50%	8,93%	**73,21%**	5,36%
Check code compliance	16,67%	10,00%	6,67%	**66,67%**	5,36%	0,00%	3,57%	**91,07%**
Evaluate conformance with program/client values	23,33%	10,00%	10,00%	**56,67%**	14,29%	1,79%	0,00%	**83,93%**
Detect clashes	26,67%	13,33%	3,33%	**56,67%**	35,71%	5,36%	14,29%	**44,64%**
Perform automated generation of drawings and documents	16,67%	10,00%	30,00%	**43,33%**	19,64%	3,57%	**39,29%**	37,50%
Perform multiuser editing of a single-discipline model; multiuser viewing of merged or separate multidiscipline models	23,33%	16,67%	6,67%	**53,33%**	21,43%	1,79%	10,71%	**66,07%**
Rapidly generate and evaluate construction plan alternatives	**43,33%**	6,67%	10,00%	40,00%	17,86%	3,57%	26,79%	**51,79%**
Perform automated generation of construction tasks	30,00%	3,33%	13,33%	**53,33%**	21,43%	5,36%	26,79%	**46,43%**
Perform discrete event simulation	30,00%	16,67%	3,33%	**50,00%**	14,29%	3,57%	33,93%	**48,21%**
Perform 4D visualization of construction	30,00%	10,00%	10,00%	**50,00%**	19,64%	7,14%	**58,93%**	14,29%

schedules								
Monitor and visualize process status	36,67%	6,67%	10,00%	**46,67%**	19,64%	5,36%	**42,86%**	32,14%
Export data for computer-controlled fabrication	20,00%	6,67%	16,67%	**56,67%**	12,50%	3,57%	35,71%	**48,21%**
Integrate with project partner (supply chain) databases	20,00%	10,00%	6,67%	**63,33%**	23,21%	1,79%	7,14%	**67,86%**

4. Discussion and conclusion

The results show that, by the applied BIM education at the Faculty of Civil Engineering Košice and Zagreb, students have gained basic BIM knowledge and that students are in general satisfied with acquired BIM skills and BIM tools used in their education. Moreover, they are aware that BIM has been used less in Croatia and Slovakia than in other countries in EU.

The literature review showed that constructability, 4D scheduling, model based estimating, model based design, visualization, sustainability, communication, collaboration, clash detection and interoperability represent important knowledge areas for CM BIM education [3, 14, 15, 17]. According to research, only constructability, model based estimating and collaboration have been acquired through BIM education at the Faculty of Civil Engineering Košice but only as a theoretical knowledge. On the contrary, at the Faculty of Civil Engineering Zagreb 4D scheduling, model based estimating, model based design, visualization and interoperability have been achieved as theoretical and practical knowledge; communication and collaboration only as a theoretical knowledge while constructability, sustainability and clash detection have not been included within BIM education but represent important knowledge areas. Thus, students at the Faculty of Civil Engineering Košice and Zagreb after BIM education have had basic BIM skills required for BIM mangers/engineers and BIM project managers identified by Wang and Laite [2]. BIM education at the Faculty of Civil Engineering Košice should be upgraded with practical BIM training to teach students how to use adequate BIM tools in CM field.

Likewise, thought this research we evaluated realization of 39 specific BIM competency topics through BIM education of master level of study at the Faculty of Civil Engineering Košice and Zagreb identified by Sacks and Pikas [12, 13]. According to results BIM knowledge acquired by learning BIM processes at both faculties is generally theoretical while BIM knowledge acquired by learning BIM technology at the Faculty of Civil Engineering Zagreb is theoretical or theoretical and practical. Finally, knowledge connected with BIM technology at the Faculty of Civil Engineering Košice and knowledge connected with BIM applications at both faculties has mainly not yet included in the CM educational processes.

Besides, academic experience which has been reached through the education at the Faculty of Civil Engineering Košice and Zagreb, has been single course collaboration [24, 25] because BIM has been introduced only through one discipline within the each of university separately. Therefore, education has to be extended through two or more departments and disciplines. This extension will provide students wider knowledge about interoperability, integration, communication, collaboration and clash detection which are definitely missing at both faculties.

With this study we confirm importance of including BIM training in educational process of higher student's education while BIM education should be part of undergraduate, graduate and postgraduate study. Currently BIM is included in educational processes at many faculties but BIM training is often not adequate for real complex projects. Reasons for this can be found in inadequate and not educated staff, inadequate resources and support to make the curriculum change and that there is no space left within curricula. Furthermore, our research shows that BIM education at the Faculty of Civil Engineering Košice and Zagreb has not been directed only to software training but theoretical knowledge about BIM concept is important part of BIM training. Moreover, when develop BIM framework, BIM courses, curricula and content, student's perception and feedback should play important role [6] so our research is good start point for further development of BIM education in Croatia and Slovakia. Finally, to spread BIM education and to reach missing BIM learning outcomes, connecting BIM education with other departments on the same faculty and other disciplines as well as connecting it with real companies and projects is necessary. Once it is done, creating and adapting curricula will not be a problem while academia, students and participants from real sector will utilise all values and benefits of BIM application.

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Development of a framework to support the information flow for the management of building

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Abstract

Inefficient control of information flow in projects is one of the critical aspects that affects the entire lifecycle of buildings. Besides allowing for a simpler and more efficient transfer of information, the dramatic growth of the digitalization process in the AEC industry underlines the need for a common data environment, which manages and shares these data. The increasingly widespread adoption of Building Information Modeling (BIM) is partially leading to a union of multiple levels of information in a single digital model of the building. However, many challenges are still posed in terms of information transfer from the model to operators responsible for keeping building functioning and in good conditions. In fact, technicians could benefit from the immediate availability of data on the current state of buildings and from the level of information detail that can be obtained from digital buildings. The purpose of this work is to create a framework for data management related to the maintenance phase of the building asset. Starting from the study of maintenance processes it was possible to define the information needs that will be managed by a common data environment support associated with BIM models of buildings. Furthermore, thanks to the aid of Mixed Reality (MR), the flow of information is transferred directly to the last user both as regards geometric features and for the standard procedure to be followed. This will allow a maximum optimization of data management procedures due to an automation of processes that will result in a lower incidence of errors in the processes leading eventually to an increase in quality and productivity.

Keywords: BIM, common data environment, mixed reality, operation and maintenance, Bim Server (controllare numero max parole chiave).

1. Introduction

Information management represent one of the most critical aspect in the construction industry. The retrieval of specific data during the lifecycle of buildings in fact represents an high cost for all the stakeholders involved in this field. [1] This is even more true regarding Facility Management (FM) which is the higher cost consuming phase in the entire building life cycle and which little attention is still paid to. The digitalization process the AEC industry is attempting to put in place is a great opportunity to improve and to optimize information management. In order to do this several means of data transmission should take into consideration. On one hand the rapid spread of the BIM paradigm is showing results in terms of efficiency. On the other hand the simultaneous existing of multiple actors in the process requires tools that guarantee the data flow in real time and the interoperability between different software

Nomenclature

FM	Facility Management	VR	Virtual Reality
MR	Mixed Reality	AR	Augmented Reality

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or input format. Cloud platforms meet these needs providing virtual place users could use as a repository of data that are real time uploaded and that could be enriched with different kind of information.

This research starts from a deep analysis of issues and related needs in the maintenance industry. The possibility of performing assisted diagnoses, automatically detecting components, avoiding surveys for the collection of information, as well as the remote support to the diagnosis phase and also to complex operations are all scenarios that offer great opportunities for improvement, particularly in terms of automation, since the automation of procedures is the benchmark for the improvement of efficiency and productivity. For each of the aforementioned processes the management of on-site operations is crucial since the correct transmission of information can be decisive for the correct execution of procedures. Mixed reality represents a powerful way of communicating on-site as this kind of virtual reality can overlap real workplaces with holographic views and it allows human interaction with the digital environment created.

This work aims to demonstrate the feasibility of a system for the management of information flow using all the aforementioned technologies that, when considered separately, have already been demonstrated to increase efficiency in the construction industry.

2. Literature review

2.1. Information management

One of the biggest challenges in the construction industry today is information management both in the construction phase and in the management phase. The large amount of information necessary for maintenance has two different aspects: variety and availability. Regarding to variety, facility managers decisions require knowledge of various types of information created by different members of construction teams such as: maintenance records, work orders, causes and knock-on effects of failures, etc. This high fragmentation in the production and management of data leads to considerable difficulties in the correct transmission of data.

Another key challenge in operation and maintenance process is the need to have information on products (specifications, previous maintenance work, specialist professionals recommended for the job, etc.) ready available. [2] Moreover one aspect to pursue about maintenance data is the knowledge created from operations such as lessons learnt about the causes of failure, reasons for selecting specific method of maintenance, selection of specialist contractors, ripple effects on other building elements. [2] This knowledge produces the fundamental know-how for training new personnel and for this reason should be captured in detail.

2.2. BIM for operation and maintenance

The operational phase of a building is the main contributor to the cost of the building's life cycle. Studies show that the cost of the life cycle is five to seven times higher than the initial investment costs and three times the cost of construction. [3] It is therefore crucial to identify increasingly efficient methods for managing the life cycle of buildings.

At the same time, Building Information Modeling (BIM) has become the new international benchmark for improved efficiency and collaboration in the different phases of building life. [4]

Findings from literature show that there is agreement about the advantages that BIM applied to FM. These advantages stem mainly from:

- Improvement to the current manual process of information handover
- Improvement to the accuracy of data
- Increasing in the efficiency of work execution

These derive from the precise localization of the elements that BIM model provides and the possibility to enrich the digital models of the buildings with not only geometric information. [5] The scenario for BIM to prove to be crucial is that of emergency management in which the main data needed are of a spatial nature. During a real emergency, it is essential to have the data organized and viewed logically to respond and take appropriate action. A link from the BIM models to the FM databases could help to detect and diagnose construction equipment based on the necessary information. [4] Effective and immediate access to information during operations minimizes the time and labor and helps avoid ineffective decisions made in the absence of information. [6]

 DOI 10.3311/CCC2018-131

2.3. Cloud-based systems for information management

Several studies focus on cloud application in the construction industry because of its ability to support projects in the sharing of documents and information. Even if the BIM tools allow an improved management of information, the increase in the amount of data, exchange and sharing addresses a series of challenges. [7] Still it has been widely demonstrated that the Industry Foundation Classes (IFC) format is not able to store and transport data for all multi-phase construction processes. Therefore, the need to develop a "Cloud BIM information exchange mechanism" that allows to use only the required information of different disciplines that is what is needed in the field of building maintenance is clear. [8]

Chuang et al. [Chuang] for example, they used cloud computing to develop a visual system for viewing and manipulating BIM via the web with no time or distance limits. [10,7] One of the main advantages of cloud computing is in fact to permit exchange in real time. [10,11]

2.4. Virtual Reality for operation and maintenance

Even if as stated before, the operational phase of construction is the one that most affects the costs in the life cycle of buildings little considerations were offered to improvement and “free thinking” in the delivery of services of building maintenance [12] and this is probably due to the observation that Building Maintenance and Facility Management (FM) are seen as “non-core” functions that provide “supportive” services in organizations. [13]

As a matter of fact the latest technological applications are being experimented hand in hand with other sectors of the construction industry. In this regard one of the most innovative technology is that concerning mixed reality.

To give a definition to MR It can be said that it is any environment that incorporates aspects of both physical reality and a computer-generated reality overlapping virtual objects over a user's field of view of a real space. This made mixed reality already experimented for applications regarding the on-site support of operators, especially with regard to the need for a good training of operators and access to large amounts of information on the management of the equipment. The MR displays in fact can improve the perception of the user of the real environment showing information that the user can not directly acquired without help. [14]

Despite the great successes of BIM-based VR and cloud computing in improving the performance of AEC activities, it is however necessary to examine methods and systems to integrate both BIM virtual reality and cloud computing for advanced project communication among remote project stakeholders with a shared immersive virtual experience. [10]

Indeed the research presented in this paper is mainly focused on the integration between the BIM virtual model and the real environment and operators and on testing the mixed reality approach in three novel scenarios (inventory/survey support, diagnosis, remote support to operations).

3. Issues and Needs of Facility Management

In literature it is widely recognized that FM includes and involves multi-disciplinary activities and, as a consequence, has extensive information requirements. [4] Many references about the most important needs to be met in order to best perform maintenance interventions can be found in literature. Aided document/information retrieval, components localization, procedure management automated support, personnel training and automated identification and modelling of components represent field of greatest interest. Aided document and information retrieval is based on the use of BIM software for modelling buildings. The digital model as stated before can contain different types of data in addition to the geometric ones. Furthermore, the digital model could be supported by cloud data storage systems for procedures or extended information that cannot be inserted into the model. [12,15,16]

In literature it is possible to find researches attempting to identify information needed for buildings maintenance management. This information depends largely on the type of facilities and on the operations to be carried out. Among the necessary data, Hamledari et al. indicate the details associated with the inspection process, such as the person/organization responsible, defects, as-built type, as-designed type, data capture tools, time/date of the inspection, the inspector’s notes and the images captured [17]. Gao et al. begin, instead, from a more detailed analysis of the components to be detected on-site, starting from the OmniClass classification and integrating it with data fields in a COBie worksheet [18].

A further informative requirement concerns the localization of the component. Conventionally, maintenance personnel on-site rely on paper-based blueprints or on their experience, intuition and judgment in finding and locating equipment. The BIM as-built model can be of great help, also considering the clear visualization that the 3D model provides. [4,19]

Another kind of information which is crucial is the one regarding the procedures to be followed: which maintenance and repair works must be performed, when these works must be done, how work can be undertaken safely and which works are most needed. [12] These information requirements are all included in the training of personnel, who are currently managed through presentations, on-site visits, hand-hand demonstrations and self-study, which takes a long time and depends largely on the skills and experience of the trainers. [4] This would certainly benefit from organized data management and advanced visualization and support tools. [20,21]

Lastly, the real geometry of buildings often differs from the original plans and for this reason the reconstruction of a precise 3D model is a common requirement. The efforts in automated modelling have so far focused on the segmentation and recognition of large structural components and more strongly for the exterior rather than for internal components. In addition to this, recent research focused more on capturing geometric data rather than semantic representations of buildings. [22, 24, 25, 26, 27, 28] In general, although this proves to be a demanding task, so far relatively few studies have turned their attempts to reduce modelling/ conversion efforts from construction data acquired into BIM objects with a high semantic meaning. [20,21,29]

4. Proposed Method and system architecture

The deep study of the FM issues and needs points out many challenges the construction industry should face. Starting from these the research continues collecting additional information needs using surveys with maintenance personnel. Meetings with operators let also to identify commonly used procedures and gather all the information requirements necessary to effectively perform the critical processes previously identified. Those data requirements represent all the data that must be implemented in the BIM model of the building.

The framework proposed (Fig. 1) is composed of different methods that carry information in different ways. The first one is represented by the BIM model containing all the data necessary for the operations. Then a cloud database has been detected as the right tool for the management of large amounts of data. Furthermore, cloud databases allow building models to be enriched with information also in different formats from the IFC. Finally, since the management of all the maintenance data has to be real time, in order to be useful on site and constantly updated, the possibility of the cloud data to be online is decisive.

The last tool is the mixed reality on site. This requires to develop interfaces between the previous methods (BIM,cloud) and virtual data. Since the aim of this research is to enable the flow of information regarding buildings, as far as the FM critical processes identified are concerned, these data should flow from office to operation site and vice versa. Therefore the interfaces between mixed reality and data collection systems should allow on one side to display the useful information on-site, on the other they has to register and transmit information.

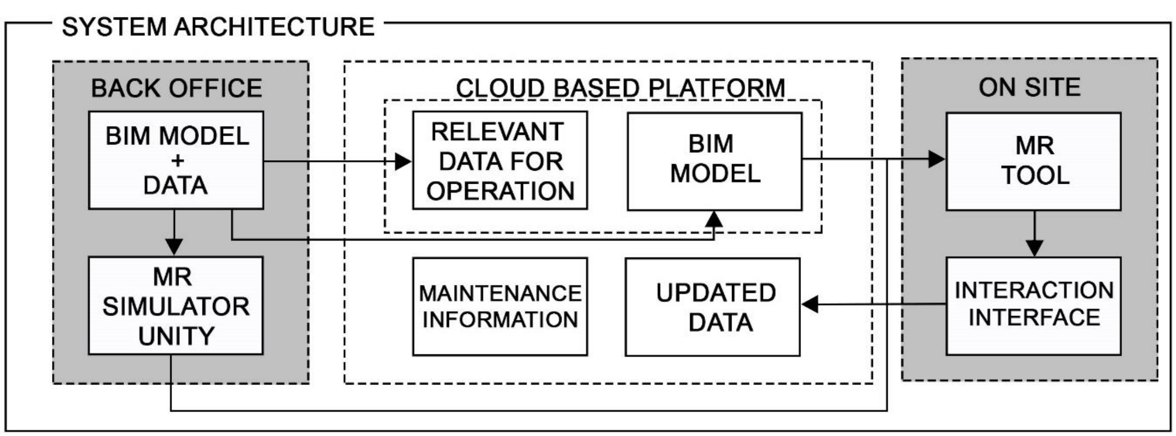

Fig. 1. System architecture

The three different methods correspond to the three different components of the system architecture: the back-office, the cloud-based platform for big data management, and the operation site (Fig. 1).

Starting from the back-office, this is the place where all the documents (BIM model, data sheet, etc.) are collected and examined to give support to the operators on site.

The cloud-based platform is the place where the BIM model updates and other kind of information are shared.

The on-site part of the system makes available equipment to provide the technician with the MR view and the interfaces that makes possible the information transfer.

4.1. Cloud-based system – Bim Server

Despite the fact that the AEC industry is information dependent communication still take place mostly by paper. [30] This way of managing data makes it very difficult the retrieval of information and it is often stuck to the physical location of documents discouraging sharing.

Cloud platforms key benefit is their accessibility from any location. This means that every participant to building management can have access to all the information everywhere. Furthermore using the same platform involves having a single virtual space where sharing data.

The choice of the use of a cloud based platform to support data flows depends also on the need of having a schema that allows fast and efficient queries among data coming from different technologies or with different purpose and, as other researches have shown, IFC is not a suitable choice for real-time applications [31]. The cloud based platform chosen is BimServer. This provides the possibility to carry out all the operations described above, thus facilitating the interoperability between different platforms. The BimServer platform provide the possibility of doing queries and it allows attaching also files from a variety of sources.

In order to choose necessary information for maintenance operations to be included in a cloud system, two aspects must be taken into consideration: on the one hand, a specific in-depth analysis of the components, containing all the technical information necessary for the interventions, and, on the other, the procedures that the personnel must follow to complete the operations.

4.2. Information flow management

The main focus of this research is on the effective management of the information flow in the construction industry and in particular for what concerns FM.

As far as the FM essential tasks are concerned the information flow regards not only single pieces of information but it is usually referred to knowledge packages necessary to perform operations. Current practices still make it difficult to capture and reuse knowledge. These difficulties in the capture-retrieval-reuse phase is for the most part due to the fragmentation of the construction processes. [32, 33]

The system proposed try to solve this challenge by mean of a continuous information flow through the different components of the system itself.

The cloud platform represents the repository where the data coming from the different sources converge. On one side there is a two-way flow from the back office, thus from the documents that provide the information base for those who perform operations on site, passing through the cloud. On the other hand, on-site applications provide an update of the data that passes through the cloud back to the office. The interfaces between the different systems guarantee interoperability and allow the different participants in the processes to collaborate.

The final flow will move in both directions, from the office to the site and vice versa, thus allowing a continuous exchange of data, which will make it possible to have continuously updated documents and the perfect knowledge of the asset status.

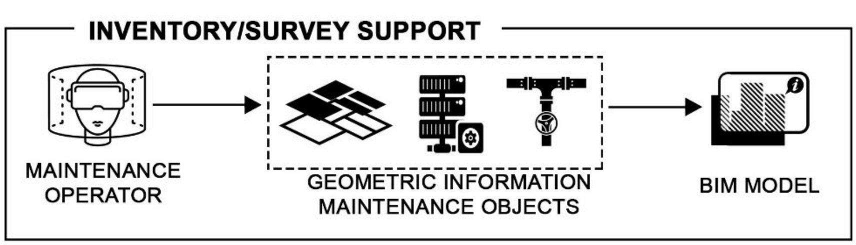

Fig. 2. Inventory/survey support

4.3. On-site development and testing

The development of the on-site section of the system proposed is carrying out with the support of the MR. The MR functions, provided by a head-mounted display, give the possibility of seeing through a screen which is capable of presenting 3D objects on top of existing physical surfaces. [34] This is made possible thanks to automated localization that the tool performs even without the use of markers. The holograms overlapping the reality are instead provided by element modeled in Unity Game Engine. Starting from the BIM model it is possible to export an FBX file which Unity can read. Once all the object are uploaded in Unity it is possible to add controls to them and finally develop application to run holograms on the head-mounted display. With Unity modeling MR enables also maintenance personnel to interact with the building and with virtual building objects, thus, pushing mixed reality towards a necessary goal so as to promote its widespread use [10]. This interaction brings also the possibility of capturing real-time data (e.g. updating maintenance operation results) which, in turn, allow constant updating of the model leading to having the updated version of the digital building all the time.

After the development of this system the study expected a test phase in order to verify the proposed method. The aforementioned analysis of the current methods adopted in the maintenance industry has focused attention on some criticalities only partially solved to date. Starting from these three different ways of use the system have been proposed in order to test the information flow management and the on-site support. A first test will be performed in a predefined environment. This will try out the reliability of the system, it will be used for its calibration and for verification of main functions. At a later stage tests will be achieved in the real world and in new environments to put to the proof also the remote support. This will test the system reliability with possible source of interference.

4.3.1. Automatic inventory/survey support

The creation of BIM models of buildings, especially when talking about big structures, demands lot of time and it also has high costs. Regarding to existing buildings there is also the need to collect a large amount of information essential for maintenance operations. This turn out to be a hard task since usually as built documents does not exist or are unreliable. In addition to this some information is difficult or impossible to find [16,21]. In recent years more and more studies are being carried out about faster and more efficient survey techniques. [20] Often, however, these applications do not allow automatic transfer of data to the BIM model. [29] This is due to the fact that the captured data are not related to BIM objects and they could not even be translated in IFC.

For all these reasons the first application taken into consideration is the one regarding the automated acquisition of the data which the information flow will be based on Fig. 2. Collecting point clouds or generic surface with any construction meaning need a laborious work of data interpretation. The innovative contribution of this research in the survey is to work exactly with IFC objects and with their features, trying to minimize the post-collection efforts.

In order to achieve this goal an in depth analysis of the relevant attributes of objects under maintenance is pursued.

The support provided in this case by the MR tools resides in the possibility of automatically detecting information on site and being able to transmit it in real time to the online database.

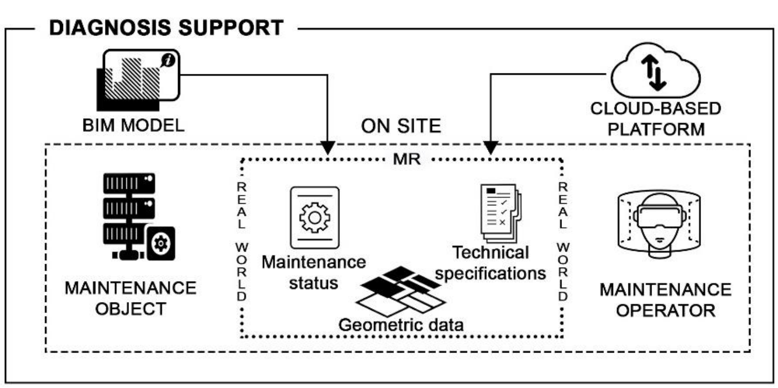

Fig. 3. Diagnosis support

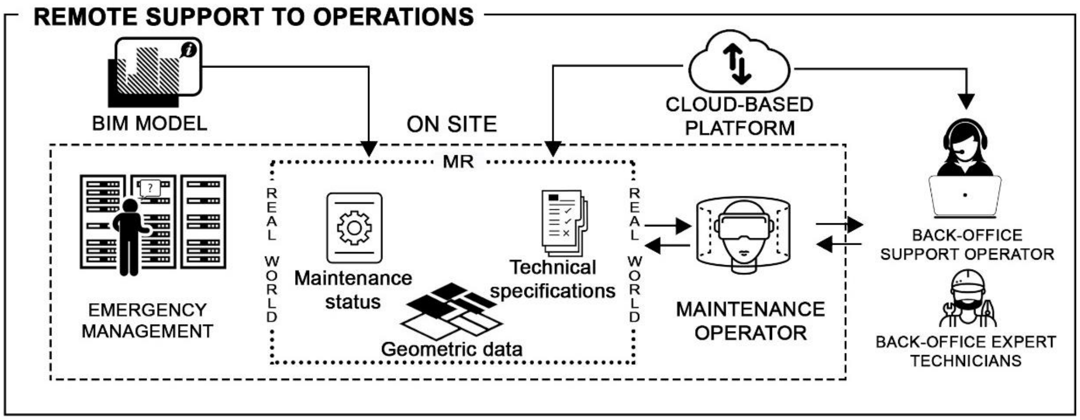

Fig. 4. Remote support to operations

4.3.2. Diagnosis support

The second task this system could bring benefits to is that of diagnosis (Fig. 3). Correct and immediate localization of objects on which is necessary to operate is an operation that requires more time and it involves a greater possibility of error in complex buildings. The mixed reality display viewer avoids having to rely on paper documents, thus making the possibility of error lower, helping in locating objects and providing all the necessary geometric information.

Moreover MR capability to overlap virtual reality to real things allows maintenance personnel to see hidden things (e.g. steel in the concrete or cable paths in the walls or behind the floor).

In addition to geometric data, there are also technical specifications and descriptions of components to be updated and stored after operations. The diagnosis task could receive a great support also from the visualization on site of causes analysis of defect, ontologies in this regard already exist in literature, which could be linked to BIM object and displayed on site.

All the data mentioned start from BIM and cloud databases and can then be visualized thanks to a head-mounted display and be always available on site.

4.3.3. On site operation support

The last scenario taken into consideration is that of on-site operations support from back-office (Fig. 4).

In case of standard operations procedures to be followed can be shown through the MR on-site. This initially implies a careful collection of the current procedures. These data are in fact part of the information package to be included in the database. Having the possibility to consult the standard procedures with this method on site, as well as reducing errors, also shorten training time for new personnel.

However sometimes it is not possible to reduce maintenance operations to a standard procedure displayed as an object property. For instance in case of emergency, a standard procedure to be performed is not always available. These are the circumstances in which real time decision support can be fundamental. The back-office consulting of experienced personnel can be decisive and the powerful visualization capabilities of the digital viewer allow to share information and images in real time.

Moreover, sometimes not all information can be displayed automatically, because it would result in having a large amount of bulky data to be handled on site. In this case, remote support can be of great help for all the information that would be complicated/ difficult to find automatically, which is more efficient than asking a colleague working remotely (e.g. the pieces out of production in stock).

5. Conclusion

The aim of this research project is to provide support to the information flow during the building lifecycle. This study focuses on the possibility of a combined use of three big technologies, the BIM paradigm for data management, a cloud-based system for managing information flows and mixed reality, to obtain an interaction between operators, digital model of the building and information flow.

A data set, not covered by this project, that could be developed in the future is that related to the building functional data and therefore the management of on-site safety, an issue that is always very important, since it aims at reducing risks at the workplace.

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Developing an Interoperability Framework for Building Information Models and Facilities Management Systems

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Abstract

Despite the fact that the value of extending Building Information Modeling (BIM) implementation through the operations and maintenance phase is simply to reduce the operations and maintenance costs associated with inadequate interoperability, facilities management information flow is neither automated nor seamless. Facility managers do not normally use BIM models data, since they claim that BIM models either do not include their information requirements, or contain a huge amount of superfluous data which makes the data exchange process tedious and overwhelming. Construction Operations Building information exchange (COBie) is developed to improve the facility data handover and to support facilities management systems. However, COBie add-in existing applications have their inherent limitation to generate all facilities management required data, particularly spare, resource and job data sheets, in which a manual data entry is still required. Through a series of interviews with industry practitioners, this paper analyses current data exchange practices as well as proposed a conceptual interoperability framework for seamless data exchange between BIM models and facilities management systems. A proposed database information system that automatically generates a rich COBie spreadsheet by linking BIM data models via the Industry Foundation Classes (IFC) model to facilities management information provided by various sources. The proposed framework supplements the existing body of knowledge in facilities management domain by providing a system that facilitates seamless data transfer between BIM and facilities management systems. Facilities management organisations and owners can use this approach to decrease the redundant activity of manual data entry and focus their efforts on productive maintenance activities.

Keywords: BIM, COBie, data exchange, facilities management, interoperability.

1. Introduction

For a Facilities management (FM) team with multiple projects to manage, effective management of facility assets is a necessity for sustaining the maintainability, safety and reliability of a facility assets, which in turn supports organizations to achieve sustained level of operational productivity and safe working environment [1, 2]. Knowing that the Operation and Maintenance (O&M) is the longest and most expensive phase during the facility's lifecycle; which constitutes about three times the construction cost [3], accounts for (75 – 85%) of the total costs spent over the building lifecycle [4, 5], and holds the responsibility for major organization assets that often forms (35 -50%) of its balance sheet [6]. Thus, controlling O&M costs can have a considerable impact on the industry in terms of trillions of dollars of cost savings [7]. The key challenge for FM team, is to have an accurate and comprehensive information system that enables capturing and retrieving building components and systems data [8, 9].

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In most current practices, FM data is collected from paper handover documents and is re-entered manually in one of the computerized information systems such as "Computer-Aided Facility Management (CAFM)" and "Computerized Maintenance Management Systems (CMMS)" [10]. Most of the existing information systems that support FM operations often develop gradually during the O&M phase, and reside underutilized in disparate databases that often lack interoperability capability [10, 11]. Moreover, the manual entry of FM data into different individual systems is costly and time consuming process which can be extended up to six months to finalize this task [12, 13].

According to the National Institute of Standards and Technology (NIST), two-thirds of the estimated $15.8 billion lost in the U.S capital facilities industry are associated with inadequate interoperability during the O&M phase, to cover for expenses related to manual data re-entry, data verification, redundancy and idle labor time finding relevant data that is often unavailable [6, 12, 14].

Building Information Modeling (BIM) can offer an information conduit and repository to support FM activities [15]. BIM proved its success in design and construction phases, but also proved its invaluable potential to support FM team during the O&M phase [13, 16-18]. Governments such as those in the UK are driving to promote a potential improvement for data handover process in the form of COBie to support its BIM Level-2 mandate [19-21]. BIM can potentially enable data sharing and exchange between different stakeholders during the facility's lifecycle [22]. Yet in the most current practice, over (70%) of completed construction projects fail to deliver BIM models and corresponding COBie spreadsheet at the project's handover stage for the owner and FM team use [23].

Studies of current FM practice show that most of BIM models data is often created and accumulated throughout the design and construction phases of the facility and does not necessarily take full consideration of FM requirements to support its operations [24]. Moreover, there are commercially available technologies focus on transferring data between BIM models and FM systems, but the process of pushing BIM models outputs to FM systems inputs is not a straightforward process or cost effective. There is a need for best practices for data transfer strategies to be developed and documented. Therefore, in this research, we propose a conceptual interoperability framework for data exchange by linking BIM models outputs along with various stakeholders' outputs to FM systems inputs. In our approach, the system is developed through an intelligent external database that enables various data sources to be added and retrieved. The proposed approach processes FM data provided by different stakeholders along with specific outputs extracted from BIM models to automatically generate a rich COBie data spreadsheet that includes most of the required outputs to support FM systems.

1.1. Facilities management information

Today's facilities are ever more sophisticated and the need for available and reliable information for O&M activities is vital [6]. Most of this needed information are often created and accumulated throughout the design and construction phases and is often handed over to the owner/ FM team when the construction is completed in the form of paper and/or electronic copies. This late delivery of unstructured data, causes a serious challenge for owners/FM team to check and verify whether the delivered information includes FM requirements in order to perform their activities efficiently [10, 13]. It is acknowledged that BIM improves information management during the O&M phase [10, 8]. The more accurate and real-time information is available for facility managers, the greater the opportunity for the enhancement of processes throughout the O&M phase. One of the key success factors for BIM implementation in FM, is to identify the required data for FM team day-to-day activities [26, 27].

Accordingly, the industry started to acknowledge the importance of having a standardization for data format and specification and issued standards that support data management such as PAS 1192:1,-5 to improve semantic data interoperability. For example, COBie standards were developed to improve the facility handover process by providing a non-geometric structured data available for the FM team use [28 - 30]. However, according to Love, et al. [31], COBie and the FM Handover MVD "provide a structure for the information the owner needs, but they do not support the owner with what to populate them with in order to receive value later in the lifecycle". Thus, identifying the required BIM data outputs for FM systems inputs is critical [32]. Several studies tried to tackle this topic and highlighted the necessity of identifying the required FM data. Becerik-Gerber et al. [11] listed the application areas of BIM in FM and clarified how each application requires a specific data requirements. Sattenini et al. [33] attempted in their research to identify the required FM information to be considered in BIM models using a case study approach of a university building. Mayo and Issa [34] investigated the required non-geometric building information to support FM operations through a Delphi panel of FM experts. While Cavka et al. [35] conducted a study using a university building to identify the required data for maintenance, systems monitoring and assets management activities. Finally, a study conducted by Dias & Ergan [36] identified the required data for HVAC systems maintenance. Most of the researchers mentioned that data requirements vary according to the building use and owner requirements. However, having a standardized approach to identify data requirements for FM team use remains challenging.

1.2. Data exchange and interoperability

Theoretically, BIM works as a collaborative platform that facilitates an automatic seamless data flow between different stakeholders throughout a facility's lifecycle [37], and eventually, provides FM team with an accurate and reliable information database [38]. However, in actual practice, data flow is neither automated nor seamless and FM team still key relevant data into their computerized FM systems manually [38, 39]. Although standard data formats are capable of exchanging data between different platforms, particularly the Industry Foundation Classes (IFC) and COBie schemas, the data exchange process between BIM data models and FM systems is not a straightforward process. For instance, the integration between BIM and CAFM has been heavily criticized for limited data interoperability, particularly the ability of transferring proper FM semantic data [40]. Recent research acknowledge that, although BIM enables data flows easily among facility's lifecycle using an interoperable data formats - yet data exchange between BIM and FM systems and interoperability, remain problematic [24, 11, 40-45].

Recently, several research conducted to tackle the issue of data exchange and interoperability focused on one or two of the following topics: (1) the value of using BIM to enhance the handover process [46, 47, 31], the need to identify FM information [11, 34], (2) the use of open data standards such as COBie and IFC to transfer data between BIM and FM [46, 48 - 52], (3) the efficiency of using different technologies such as barcode and augmented reality along with BIM to improve FM operations [53-58]. The existing literature indicates that seamless facility data exchange cannot be optimized by straightforward adoption of BIM as a database tool; and it further shows that project stakeholders should also consider a new BIM-enabled processes that enable capturing facility data and then exchange it using open data formats, that allow the potential interoperability with different FM systems. Moreover, the existing literature indicates that interoperability remains a significant and persistent challenge for using BIM to support FM operations. Thus, more research is needed to further substantiate the potential of seamless data exchange between BIM and FM systems.

2. Research method

The overarching aim of this research is to develop the conceptual framework for seamless data transfer between BIM and FM systems. The development of this framework necessitates a general understanding of the current status of data exchange methods and requirements. Accordingly, we used semi-structured interviews method to collate more views from the industry practitioners on the current data exchange method and requirements. A total of 16 BIM experts participated in the research interviews from different organizations as shown in Table (1). Results of the interviews helped in outlining the general approach for the proposed interoperability framework as discussed in section (4) and presented in section (5).

3. Research results

Interviews transcripts were analyzed using a thematic analysis approach. The interviews covered two themes: (1) data handover process deliverables; (2) data exchange methods and requirements. Interviewees were selected from different industry stakeholders to collate different perspectives as presented in Table (1). Interviewees representing FM organizations formed (37.5%), followed by interviewees representing both contracting and BIM consultancy organizations (25%) each, and interviewees representing architect/engineering organizations (12.5%).

Table 1. Interviewees' demographic distribution

Interviewees' organization type	No.	Percentage (%)
Facility Management	6	37.5
Contracting	4	25.0
Architect / Engineering	2	12.5
BIM consultant	4	25.0

3.1. Data handover deliverables

Interviewees were asked about projects' data handover required deliverables using BIM, and most of the interviewees chose at least three deliverables out of five provided. All interviewees (100%) mentioned that the electronic copy of scanned construction documents (EC) and BIM as-built models (BIMS) were required for handover. While (56%) of the interviewees stated that paper copy of construction documents (PC) was required as well, and (50%) of the interviewees added COBie as another deliverable as shown in Fig.1. Only (6%) of the interviewees added IFC file as a handover deliverable.

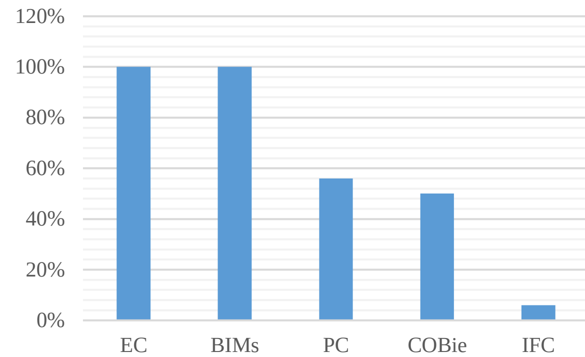

Fig. 1. Handover deliverables

Interviewees were asked about how they hand over data related to periodic preventive maintenance, spare parts and operating environment issues. All interviewees agreed that this type of data is normally delivered within the O&M manuals as a scanned electronic copy (.pdf).

3.2. Data exchange methods and requirements

Interviewees were asked about data exchange methods which were used in their projects to transfer data between BIM and FM systems. The majority of the interviewees (56%) stated that data was transferred manually although BIM as-built models were delivered to the owner. While (19%) of the interviewees stated that they used either a middleware software such as Ecodomus or COBie spreadsheet as presented in Fig.2. While (6%) of the interviewees presented as "other" clarified that they used other methods such as BIM 360 environment to share data with FM team.

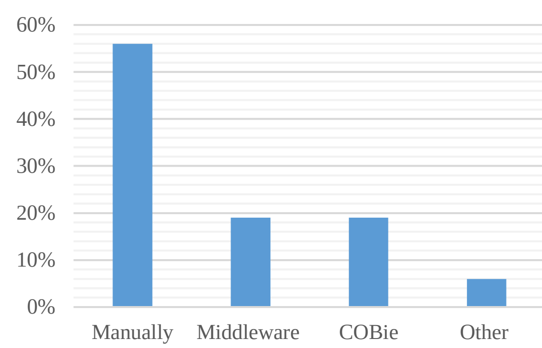

Fig. 2. Data exchange method between BIM and FM

Interviewees were asked about their opinion of the most efficient method to transfer data seamlessly between BIM and FM systems. Most of the interviewees as presented in Fig.3. (63%) selected COBie. While (19%) of the interviewees indicated that IFC is more efficient for data exchange process and (13%) stated that FM systems vendors should start thinking about direct integration between FM systems software and BIM models. Only (6%) of the interviewees found that a middleware software can be the best method.

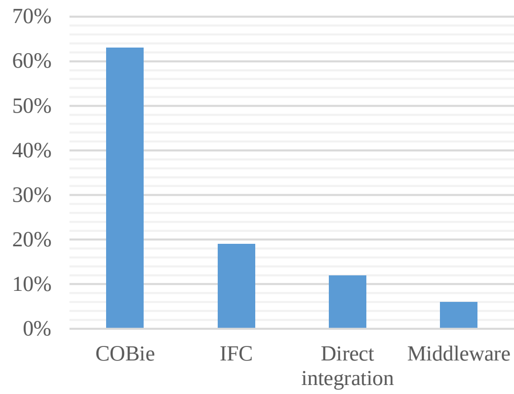

Fig. 3. The most efficient data exchange method between BIM and FM

Finally, the interviewees were asked if COBie spreadsheet includes all required FM information. All interviewees agreed that COBie add-in existing applications do not generate all the required FM information. Furthermore, the interviewees were asked to give examples of the required information which are not included in COBie spreadsheet, these examples are: periodic preventive maintenance schedules, spare parts, legislative compliance requirements, consumables and safety issues. The interviewees were asked then to list the required BIM outputs for their FM systems inputs and they listed different types of data as presented in Table (2).

Table 2. Interviewees' feedback on the required BIM outputs of FM system inputs

Items	Required information
Maintenance management	Maintenance schedules (preventive and reactive), Legislative compliance requirements
Asset management	Asset register, Asset ID, Description, Location, Type, Subtype, Bar code, Classification, Rotating item, Serial #, Warranty information, Tag #, Specifications, Spare parts list,
Planning and scheduling	PM activities, Durations, Frequencies, Resources (tools, labor and material)
Supply chain management	Vendor information, Manufacturer information, Installation date, Replacement cost, Expected useful life, Purchase order # , Consumables
Health and safety	Codes and requirements

4. Discussion

The interviews results shaped the general understanding of the current status of using BIM to support FM operations. Interestingly, interviews results show that for some projects where BIM is used to support FM operations, manual data entry was used to enter FM data into FM systems software. Interviewees clarified that COBie and BIM as-built models were stated clearly in the Employer Information Requirements (EIR), but FM team opted to enter data manually into their FM systems as they could not manage to deal with COBie spreadsheet. On the other hand, interviewees who used COBie as a database for their FM systems asserted that COBie spreadsheet did not include all FM required data such as the preventive maintenance data in which they had to enter this data manually into their FM systems. Therefore, having a seamless data exchange process between BIM and FM systems will save a considerable amount of time and effort.

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5. Conceptual framework

Analysis of the data confirms the importance placed by industry professional on potential seamless data transfer between BIM and FM systems, and how specific asset information requirements are needed to reduce the redundant effort of generating BIM outputs that don't match the FM systems inputs. Fig.4. shows a proposed seamless data transfer process using specific asset information requirements to be considered in BIM models and then export these required outputs to external intelligent database using IFC schema. Other data related to preventive maintenance and spare parts will be added to and retrieved from the same database using various sources such as the industry standards (SFG20 .xml) and spare parts spreadsheet .xlsx. A rich COBie spreadsheet will be generated using COBie-lizer module to include FM data requirements.

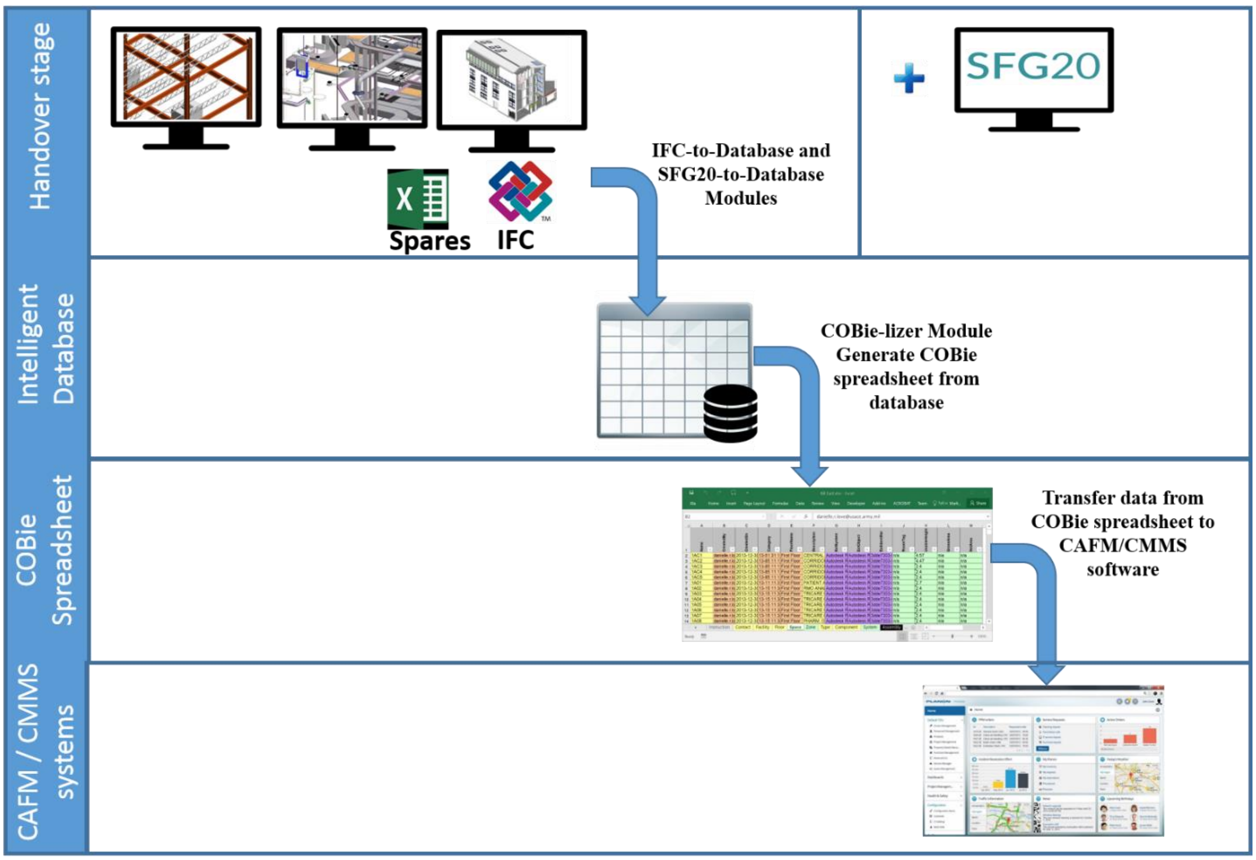

Fig. 4. The conceptual framework for seamless data exchange between BIM data models and FM systems

The proposed framework consists of the stages and inter-stage processes detailed below:

- **Stage I:** At this stage in the project's life cycle, facility data has been captured at different phases by various stakeholders, and stored in the form of a BIM model. These BIM as-built models include a huge amount of both geometric and non-geometric data about the facility. This data can be obtained from the model in the form of IFC (design deliverable view) as shown in Fig.5. which the majority of BIM-enabled authoring tools are capable of producing. The first component of the proposed framework is to process the IFC file into entities ready for storage in a relational database.

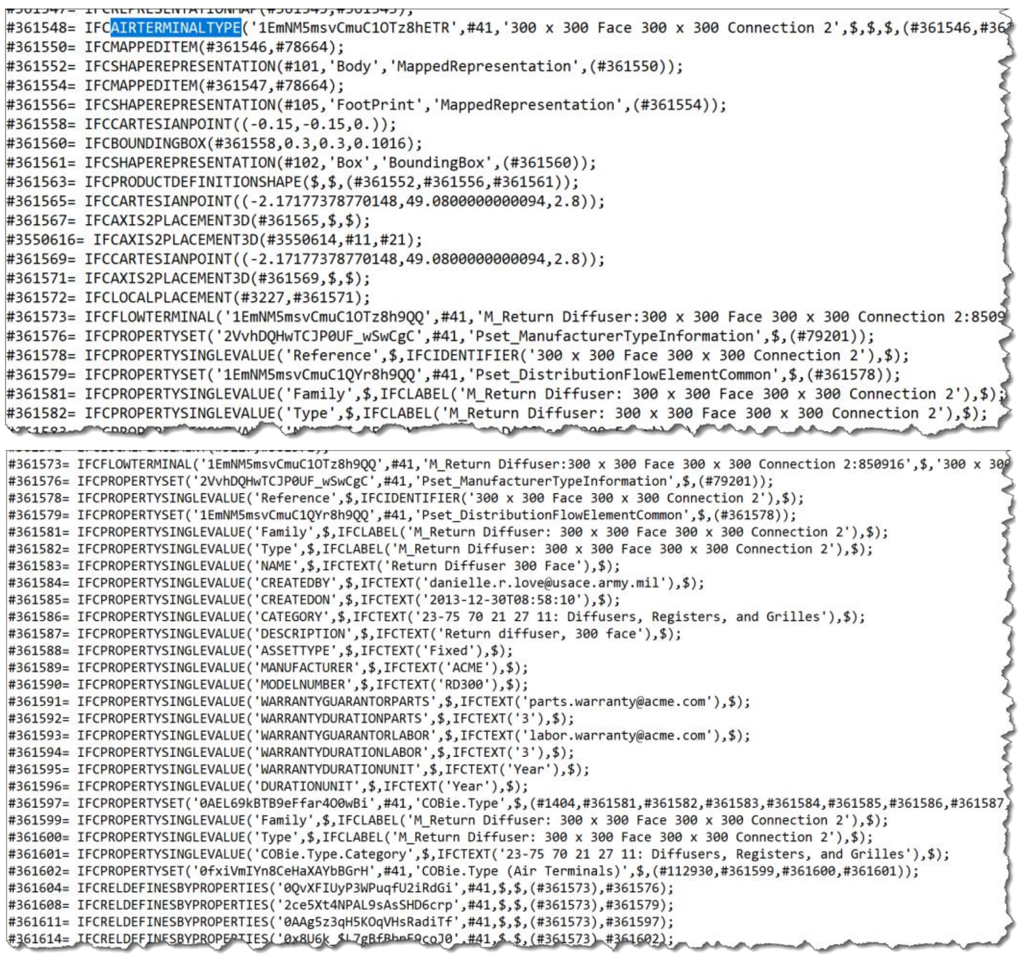

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Fig. 5: IFC2×3 COBie 2.4 Design Deliverable View

- **Stage II**: Unfortunately as discussed previously, some of the required vital data relating to maintenance is not included in the BIM as-built model IFC files. The required data can be collated from various sources such as SFG20 (the de-facto maintenance standard) which includes preventive maintenance schedules (actions, durations, frequencies and resources) and related legislative compliance requirements as shown in Fig.6. Spare parts log is another data source usually prepared by the general contractor during the construction phase for handover in the form of a spreadsheet. This spreadsheet now resides outside the 3D BIM model and hence not included in the IFC file during export. All data collected at this stage is inputted to the external database for further data manipulation.

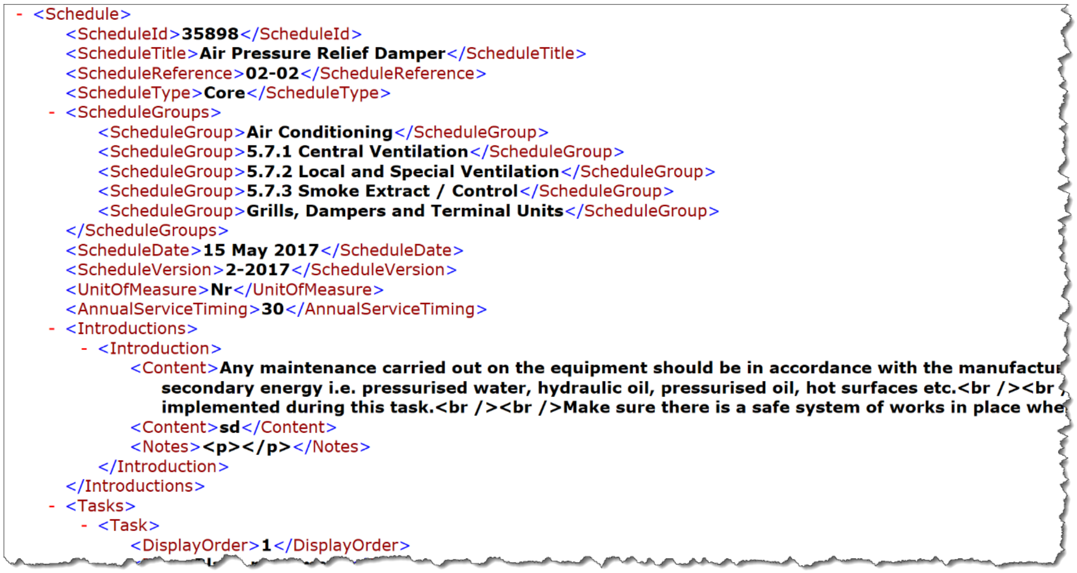

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Fig. 6. Exporting SFG20XML

- **Stage III**: At this stage, the external database would have been fully populated with data from the IFC files, SFG20 data schema and any auxiliary spreadsheets such as the spare parts logs. This rich data is then processed through the proposed COBie-lizer module which takes in these inputs and automatically generates a fully compliant COBie spreadsheet. This COBie-lizer module will be developed based on relationship-mapping between the external database and COBie sheet schema.

- **Stage IV:** At this stage, there are full sets of COBie spreadsheet data developed from stage III. With COBie being an internationally accepted standard for managing asset information including space and equipment, direct data transfer between COBie spreadsheet and CMMS/CAFM software can be done seamlessly.

6. Conclusions and recommendations

Through the development of the proposed conceptual framework, we have come to understand the importance of interoperability between BIM models and FM systems and advocate the focus on the development of seamless data transfer process within the research community. A key question in this area is, "to what level can data be transferred and managed seamlessly between BIM models and FM systems?" Asset Information Requirements (AIR) which have mainly focused on room numbers, floor areas, space use and asset register, can host more relevant building maintenance data such as preventive maintenance outputs. Moreover, the participants' feedback assert the general understanding that data exchange between BIM models and FM systems is not a straightforward process. Managing a huge amount of data collected from various stakeholders using COBie data structure is helpful – yet the existing COBie add-ins applications do not allow for automatic generation of all required FM data. Accordingly, we developed a conceptual framework that allows for the required data to be collected and retrieved at different levels and then transferred seamlessly to the FM systems using an open standard format. The proposed conceptual framework will be implemented by developing a module "COBie-lizer" to generate a rich COBie spreadsheet and then tested in future research. Findings in this domain could be of great interest to owners and facility managers who currently struggle with their current information management systems.

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Development of a BIM-based cyber-physical system for facility management of buildings

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Abstract

In the wide facility management context, several processes such as operations, maintenance, retrofitting and renovations ensure that buildings comply with the principles of efficiency and cost-effectiveness. Besides ordinary operation, facility management is responsible for renovation of building facilities and long-term improvement of their performances. In such a scenario, the cyber-physical system (CPS) paradigm with holonic architecture, that will be reported in this paper, can successfully advice the operation management of buildings, as well as long-term refurbishment processes. Indeed and in analogy with the manufacturing field, the developed CPS exploits holons self-configuration and self-organization and overall throughput effectiveness (OTE) metrics, in order to detect the best corrective actions towards system improvements. As a consequence, suggestions and lessons learnt from the evaluation of building efficiency are re-directed to the BIM model. Hence, the digital model acts not only as a repository of currently available equipment for operations management, but also as a repository of the history of the diagnoses that supports decision making during maintenance, retrofitting and renovation processes. As a matter of fact, the repeated detection of a specific issue, since not affected by operations management, should be read as an opportunity to act and enhance the capabilities of buildings components. According to this approach, an automatic real-time diagnosis method is tested in a test case consisting of a multi-use and large public building.

Keywords: BIM; building management system; cyber-physical system; facility management; holonic system.

1. Introduction

In the wide facility management context, several processes such as operations, maintenance, retrofitting and renovations ensure that buildings comply with the principles of efficiency and cost-effectiveness. In this field, relevant research is turning towards challenging goal, which can get real benefits from advanced data management and integration of intelligence, so as to produce cause-effect, performance and deterioration modelling, which has not extensively been surveyed, yet [1]. Although preliminary applications concerning performance monitoring have been suggested [2], there is evidence that digitalization and BIM must be further developed to be applied to improved decision making in complex facilities for refurbishment and facility management in general [1]. Furthermore, the importance of BIM in the assessment of the performances of buildings has recently been discussed, along with the possibility of using structured knowledge in order to perform inference about the health of existing buildings [3].

In this paper, a first holonic computing structure based on CPS technology is developed for indoor comfort management as well as medium- and long-term refurbishment processes of a large public building. The diagnosis is

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based on the measurement of the effectiveness of every device intended as a unit of the system of systems. During simulations, an overall throughput effectiveness (OTE) metrics measures the subsystems' performances and drives refurbishment design for their enhancement [4]. In fact, suggestions, history and lessons learnt from the OTE evolutions are re-directed to a BIM model to support decision making for the improvement of the whole building performance and design.

This paper is organised as follows. Section 2 provides a literature review of the holonic approach that was adopted in the present research. Section 3 describes the case research methodology. Section 4 provides a description of the case study. Section 5 shows the simulation results. Section 6 is devoted to conclusions.

2. Literature review

The holonic concept, which is the basis of holonic management systems, was introduced in 1967 by Koestler [5] to explain the evolution of biological and social systems. Likewise, in the real world, where almost everything is at the same time a part and a whole, each holon can be part of another holon [6]. In fact, the word holon is the combination of "holos", which in Greek means "whole", and the suffix "on", which suggests a part [7], [8], [9]. In the manufacturing field, holons are autonomous and cooperative building blocks, since they can both control the executions of their own strategies and develop mutually acceptable plans [6]. Furthermore, holons consist of an information-processing part and often a physical processing part [6], [7], [8]. The former is responsible for high-level decision making, collaborating and negotiating with humans and other holons, while the latter is a representative of its linked physical component and responsible for transferring decisions and instructions to it [7]. According to Koestler, a holonic system or holarchy is then a hierarchy of self-regulating holons that function (i) as autonomous wholes in supra-ordination to their parts, (ii) as dependent parts in subordination to control at higher levels, and (iii) in coordination with their local environment [6], [5], [9]. Therefore, holonic architecture combines high and predictable performance, which distinguishes hierarchical systems, with the robustness against disturbances and the agility typical of heterarchical systems [8]. In this way, systems' resilience is guaranteed.

The agent, which in latin is "a person who acts", is a software-based decision making unit embedded with internal knowledge. Unlike holons, no such separation of physical and information processing parts exists in agents' structure. Furthermore, whereas holons can themselves be made up of other autonomous holons, agents do not immediately apply the recursive architecture [6], [7]. A multi-agent system is made up of two or more related agents [6], [9].

Cyber-physical systems, in the manufacturing field, are systems of collaborating computational entities which are in intensive connection with the surrounding physical world [10]. The interaction between physical and cyber elements is of key importance to the purpose of this paper. As a matter of fact, cyber-physical systems, similarly to holons, consist of a cyber part and a physical part. This shared feature makes holonic paradigm a suitable approach for constructing and modelling a CPS system in the form of a holarchy. Therefore, on the one hand, a CPS system permits bidirectional coordination of virtual and physical levels and, on the other, the holarchy, with its flexibility, guarantees evolutionary self-organisation or, in other words, resilience [7]. Moreover, CPS systems provide an opportunity for changes in the physical structure to be captured and reflected in the virtual model. Conversely, changes in the virtual model can be communicated to sensors embedded in the physical world [11], [12]. To implement these concepts in real world applications, agents are key enablers, since they act as decision-making and communication entities with agents embedded in other holons and also humans [7], [8]. Holonic management systems, which have been successfully applied in the manufacturing field, can constitute a novel technology to tackle unforeseen scenario variations. Indeed, the autonomy and cooperation of their elementary units, the holons, make it possible to avoid the rigid structure of hierarchical systems and therefore respond quickly to disturbances [6].

3. Research methodology

3.1. System architecture

The holonic computing structure developed in this paper involves three development environments, Matlab®/Simulink®, SQL and Revit® (see Figure 1).

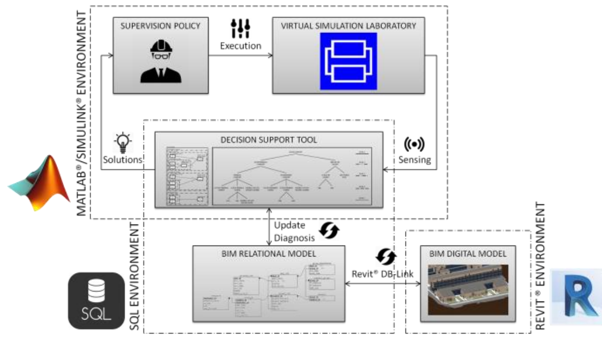

Figure 1. The architecture of the developed holonic computing structure based on CPS technology.

The Revit® environment concerns the BIM Digital Model (BIM DM), as the interface of one of the numerous BIM softwares available on the market, such as Autodesk® Revit®. The Matlab® and SQL environments share the Decision Support Tool (DST), which has the function to assess the system of systems' effectiveness and suggest a list of possible corrective actions. In details, the distributed performance metrics, inherited from the manufacturing field, defines the overall factory effectiveness (OFE), the overall throughput effectiveness (OTE) and the overall equipment effectiveness (OEE). These parameters, whose values are between 0 and 1, are effectiveness indexes referring respectively to the highest level, intermediate levels and the lowest levels of a system's tree (see Figure 2.b). Once the cells' OEE values are determined according to [13] and [4], every subsystem's OTE values are obtained following the formulas in [14]. Afterwards, by means of the Event-Condition-Action (ECA) calculation model described in [4], the DST provides, for each iteration, a list of actions towards improvement of system's performance. Note that the system's scheme (see Figure 2.a) explains its semantics exploiting the analogy with a manufacturing production line [14], [15] and could be defined as the closest representation to the humans' way of thinking. Conversely, the system's tree is the closest representation to the computing structure (see Figure 2.b).

a.

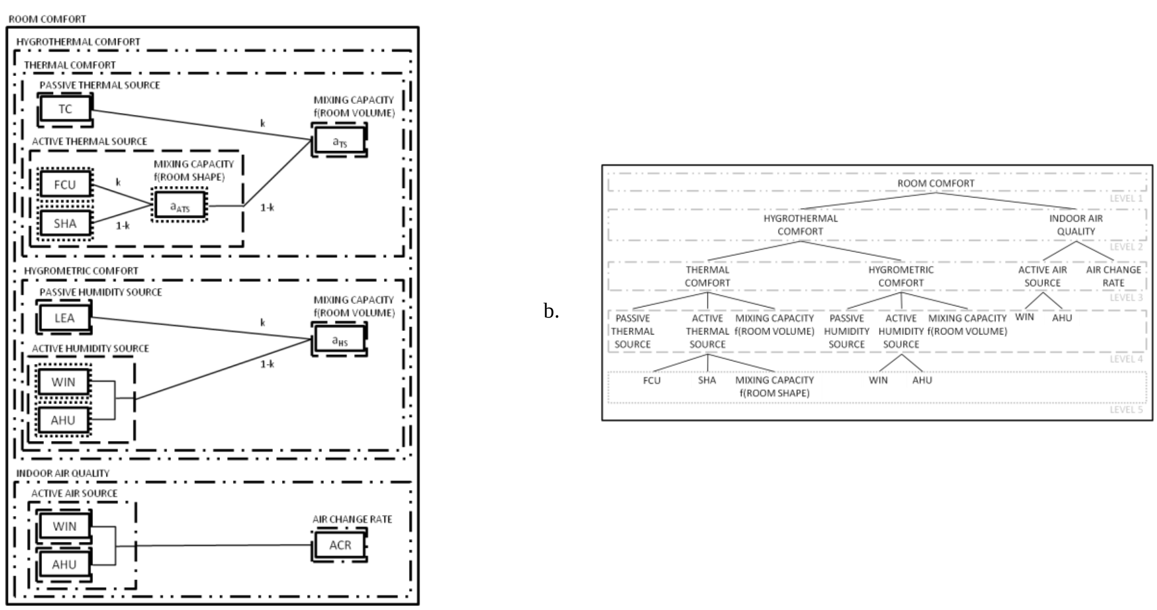

Figure 2. a. System's scheme and b. system's tree developed for the case study.

The Matlab® environment consists of the Virtual Simulation Laboratory (VSL) and Supervision Policy (SP), beside the DST described above. The Virtual Simulation Laboratory is in charge of replacing and emulating the real building by using a detailed building model. This model was developed in the Dymola® programming environment, which is based on the Modelica® Language. The building model used in this work was built upon the open-source Modelica® "Buildings" library [16] and it has the level of detail that is necessary to analyse the behaviour of each device and sub-system belonging to the building. The measures taken from the VSL provide feedback (delayed by 1 step in order to be realistic) for the decision support tool. The DST evaluates and updates the OEE of each cell by means of SQL queries, then it updates the OTE in all the system's tree and suggests a list of possible actions to the Supervision Policy. Among the actions suggested by the DST, the Supervision Policy selects and applies the one to be carried out in the Virtual Simulation Laboratory based on some internal logic/intelligence. As if sensors and actuators are distributed all around the building, the applied methodology makes it possible to monitor trends of physical variables and track inputs (normalised between 0 and 1) of corrective actions (see Figure 3).

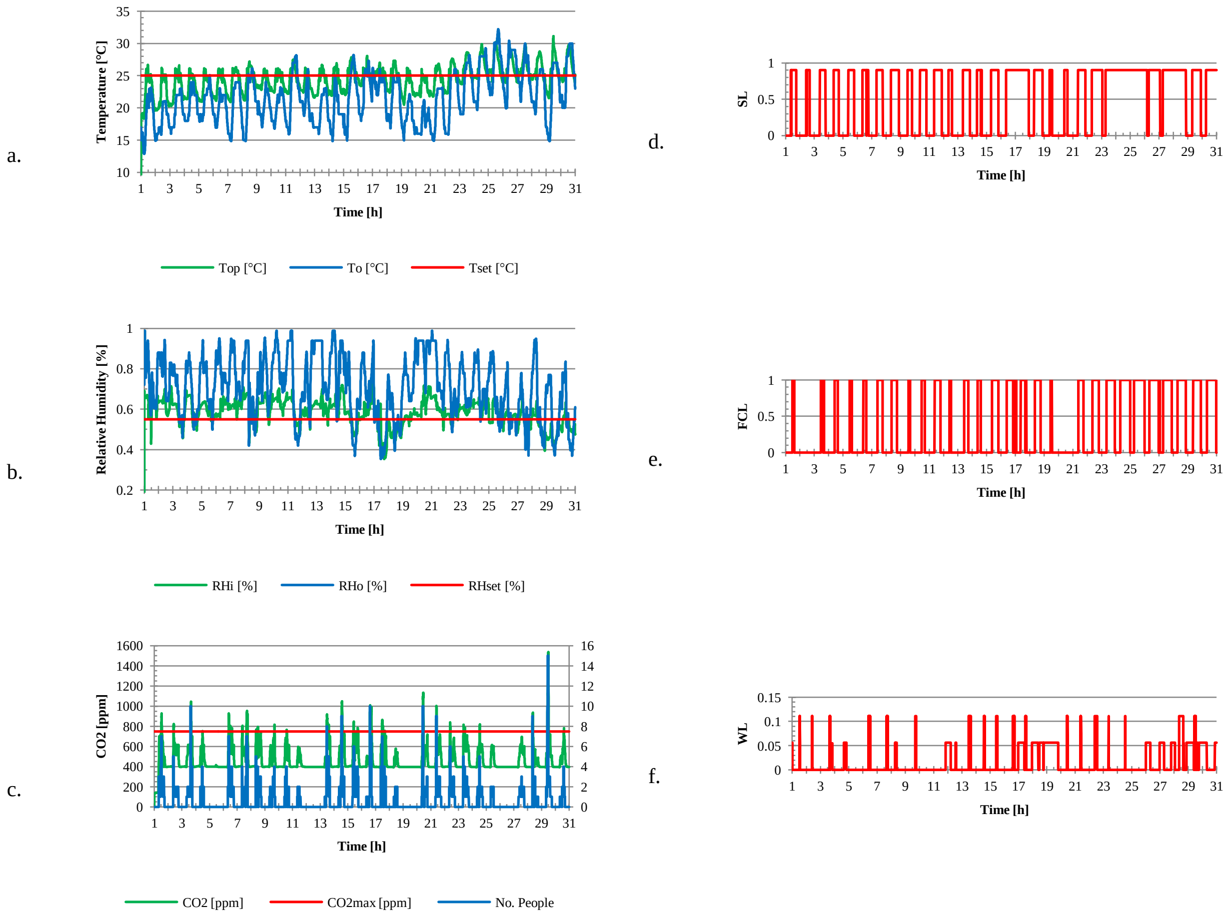

Figure 3. Operation management results for the month of June. Trends of a. temperature, b. relative humidity, c. CO_2 concentration vs number of people inside room no. 90, d. shading level (SL), e. fan coil level (FCL) and f. window level (WL).

Finally the SQL environment involves, in addition to the DST, the BIM Relational Model (BIM RM, see Section 3.2), i.e. a relational database that acts as a bridge between the DST and BIM DM and has a double function. The first function is to update the DST when the BIM DM changes. The second one is to store effectiveness data received from the DST to run building's diagnoses. The BIM RM and BIM DM exchange data in both directions, thanks to the Revit® DB-Link plug-in. In this way, the SQL and the Revit® environments are connected.

The holonic computing structure developed and implemented by integrating Simulink®, SQL and Revit® environments makes it possible to carry out any type of desired simulations away from the site.

3.2. BIM Relational Model

In this paper the BIM Relational Model and BIM Digital Model are two sides of the same coin, the practical and the formal side, respectively. The BIM DM of the building under analysis was developed using Autodesk® Revit®

and then translated into its congenital relational structure, namely the BIM RM. Hence, the BIM Model works as a repository of any types of data that belong to the building analysed.

The connection BIM RM-DST, as mentioned, provides the opportunity to define and update the scheme of the DST after changes to the building. In addition, the same link provides, in the other direction, the possibility of self-diagnosis of the holonic management system developed. Actually, the BIM model becomes a repository of the facility history or of the potential actions of improvement concerning the building. Indirectly, a bi-directional communication channel is set up, i.e. a learning phase of the VSL from the BIM repository and the storage of real-time data from VSL into the BIM model.

In order for this to happen, the relational potential of the BIM has to be fully expressed. The underlying BIM representation of the information can be leveraged and further extended to create a mapping between a relational database. Note that the full Relational Model (RM) is intended in the sense described in [17]. In the RM everything is a relational variable (*relvar*). Tables, attributes and database schemas cannot usually be operated relationally. In current SQL-based database management systems (DBMS), these operations are implemented with non-standard host language proprietary extensions for the specific DBMS implementation. By a homomorphic mapping between the BIM and its relational representation, we obtain the opportunity to develop new structured types that make it possible to record relational information and data. For example, in a BIM entity, it is possible to completely record the real-time history of parts of the building equipment as obtained from sensors. Moreover, it is also possible to record a tracking of the BIM structural changes over time. With data mining, knowledge extraction and representation techniques, some information can be grown upon, enriched, and a reasoning system can be integrated into the relational model of the building. This allows us to make BIM the core of short-term control and medium- and long-term design evolutions and adaptations on the building endowed with intelligence.

As a first experiment, the best available technology on DBMS has been used as a proof of concept. In order to interact bi-directionally with the BIM, the building digital model has been mapped to an SQL Server® DBMS using the Revit® DB-Link plug-in (see Figure 4). It permits the flow of information between Autodesk® Revit® and the DBMS in both directions. In this way BIM is updated with changes applied from the reasoner or the controller, and receives the real-time data from the virtual or physical models or the sensors. A workaround to the limited relational possibilities has been temporary created by extending some of the basic elementary BIM attributes with a numeric type that creates a primary key to some relations that can store real-time data tables or even a complete (nested) database schema.

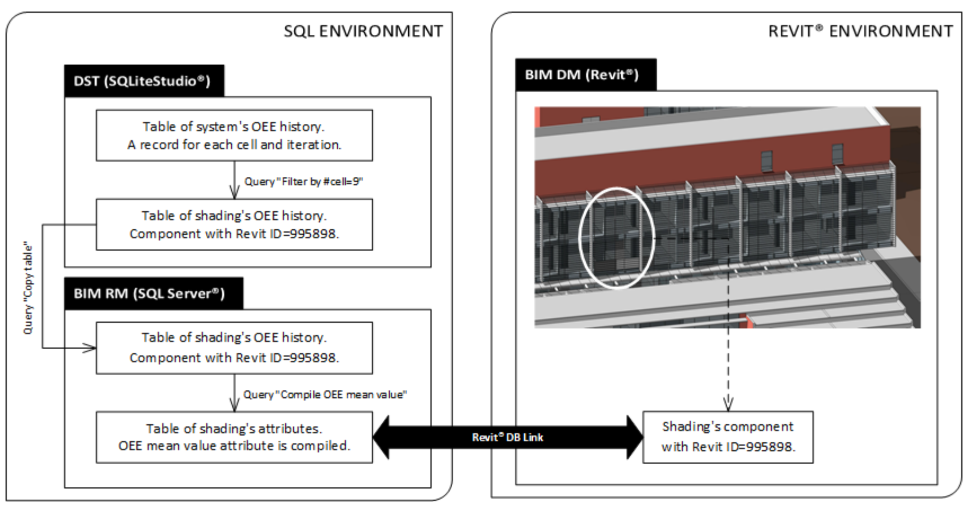

Figure 4. DST-BIM RM and BIM RM-BIM DM connections.

System's OEE history from DST, stored inside SQL Environment in a SQLiteStudio® DBMS, can be processed by queries (see Table 1) in order to make diagnoses (see Figure 4). As an example, cell 9's OEE values can be copied from the whole history into the table "ID_995898" (see "Filter by #cell=9" query in Table 1 and Figure 5.a.) and, once exported in SQL format, re-directed into SQL Server® DBMS (see "Copy table" query in Table 1). Afterward, shading's OEE mean value, updated in real-time for each iteration, can be stored inside BIM RM, filling the specific attribute inside table "GenericModels" (see "Compile OEE mean value" query in Table 1 and Figure

5.b.). Note that the shading's component in front of the case study room corresponds to cell 9 of the system of systems (i.e. "SHA" in Figure 2.a. and b.) and to the Revit element whose ID is 995898. Finally, the shading's OEE mean value can be re-directed to the BIM DM using Revit® DB-Link plug-in and displayed inside Autodesk® Revit® as a shading's parameter (see Figure 6.a.).

Table 1. Queries to process and link data in SQL Environment.

Query name	Query text
Filter by #cell=9	CREATE TABLE ID_995898 (N INTEGER, Parent INTEGER, Type CHAR, K INTEGER, Level INTEGER, OTE REAL, Rth REAL, Qeff REAL, Bottleneck INTEGER, Cell INTEGER, Iteration INTEGER DEFAULT 0);
	INSERT INTO ID_995898 SELECT * FROM systree_history WHERE Cell==9;
Copy table	CREATE TABLE [provaDBlink].[dbo].[ID_995898] (N INTEGER, Parent INTEGER, Type CHAR, K INTEGER, Level INTEGER, OTE REAL, Rth REAL, Qeff REAL, Bottleneck INTEGER, Cell INTEGER, Iteration INTEGER DEFAULT 0);
	INSERT INTO [provaDBlink].[dbo].[ID_995898] (N, Parent, Type, K, Level, OTE, Rth, Qeff, Bottleneck, Cell, Iteration) VALUES (17, 9, 'c', 0.5, 5, 1, 1, 1, 0, 9, 0);
	[…]
	INSERT INTO [provaDBlink].[dbo].[ID_995898] (N, Parent, Type, K, Level, OTE, Rth, Qeff, Bottleneck, Cell, Iteration) VALUES (17, 9, 'c', 0.5, 5, 0.0001, 1, 1, 0, 9, 8641);
Compile OEE mean value	ALTER TABLE [provaDBlink].[dbo].[GenericModels] ADD Cell_number INTEGER;
	ALTER TABLE [provaDBlink].[dbo].[GenericModels] ADD OEE_meanvalue DECIMAL;
	UPDATE [provaDBlink].[dbo].[GenericModels] SET Cell_number=(SELECT Cell AS Cell_number FROM [provaDBlink].[dbo].[ID_995898] WHERE Iteration=0) WHERE Id=995898;
	UPDATE [provaDBlink].[dbo].[GenericModels] SET OEE_meanvalue=(SELECT avg(OTE) AS OEE_meanvalue FROM [provaDBlink].[dbo].[ID_995898]) WHERE Id=995898;
	SELECT * FROM [provaDBlink].[dbo].[GenericModels] WHERE Id=995898;

a.

b.

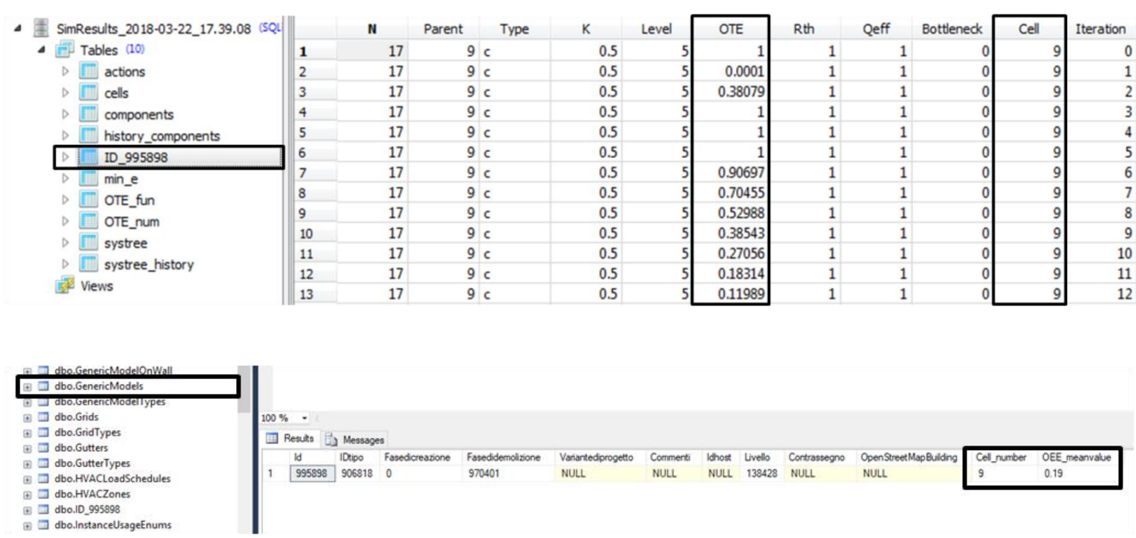

Figure 5. a. Results of "Filter by #cell=9" query applied inside SQLiteStudio® workspace (DST) and b. "Copy table" and "Compile OEE mean value" queries applied inside SQL Server® (BIM RM).

4. Case study

Eustachio building is the location of the Faculty of Medicine of the Polytechnic University of Marche, located in Ancona, Italy. This is a large and multi-purpose building composed by two main blocks, that create a clear division between the main fronts: the north and the south ones. The heating system is a two-pipe type and the air-handling system serves separately the north and the south fronts. Consequently, the building has some symptomatic discomfort problems as, for example, too high temperatures during winter, too low temperatures during summer and mid-season temperatures out of control.

In this paper, the focus is on one office room (i.e. room no. 90), located on the third level of the South front and used as an office (Figure 6.b.). Its net surface is approximately 19 m^2 and the three-modules window is about 7 m^2 large, one of which is operable. The room no. 90's air handling unit causes just air recirculation, since the humidifier is not working. The fan coil unit is a FC200 type and, for the purpose of the paper, only its cooling function in the summer season is considered. In addition, a shading system is also included. The application to this room has been used as a proof of concept for further simulations to the whole building. The described methodology (see Section 3) makes it possible to diagnose quickly the causes of building's shortcomings in term of indoor climate comfort and plan future refurbishment.

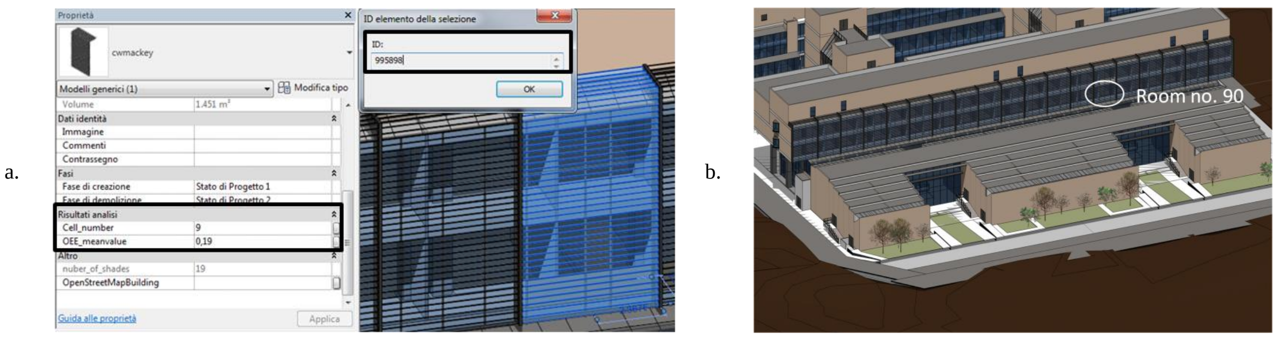

Figure 6. a. The shading's OEE mean value displayed inside Autodesk® Revit® as a shading's parameter and a. the room no. 90 in a 3D view of the Eustachio building's BIM DM.

5. Simulations results

The holonic management system, described in this paper is experienced for the month of June 2016. In this period, weather data define really dynamic boundary conditions able to strongly urge the system. The simulations for this representative scenario aim to prove the system's ability to perform not only short-term operation management in real-time, but also diagnoses of building with regard to medium- and long-term refurbishment. In fact, the holonic management system makes it possible to carry out diagnoses on buildings by focusing on the system of systems' and cells' effectiveness mean value. In details, BIM RM can:

- store system of systems' time data, such as OTE/OEE time values, creating a repository of the facility history;
- store (see Figure 5.b.) and re-direct their mean values, which are continuously updated according to the last iteration, to the BIM DM (see Figure 6.a.) in order to visualise them inside Revit® environment (e.g. during refurbishment design of building).

Low monthly mean values of OTE and OEE highlight entities that cannot pursue the assigned target towards room comfort. Figure 7 shows OEE monthly mean values (June 2016) for the system's *cells* (the leaves of the tree, see Figure 2.b.). The histograms point out the highest effectiveness of Indoor Air Quality sub-system. In fact, the room assumed as case study has a good air change rate (OEE_{ACR} = 0.89) and window ($OEE_{WIN(IAQ)}$ = 0.76) and air handling unit ($OEE_{AHU(IAQ)}$ = 0.86) ensure a satisfactory ventilation in June. Whereas, the room's external partitions are not effective in terms of thermal conduction (OEE_{TC} = 0.15) for indoor thermal comfort, since they are made of glass and metal. The shading (OEE_{SHA} = 0.19) and fan coil unit (OEE_{FCU} = 0.31) show possibility of improvement, since the former can be extended to the whole glass façade (both the transparent and the glazed part) and the latter can be boosted up. Results about hygrometric comfort point out how the window ($OEE_{WIN(HC)}$ = 0.11) and air handling unit ($OEE_{AHU(HC)}$ = 0.17) does not ensure a good enough contribution to optimal indoor relative humidity and room's external partitions are not effective, because of air leakage (OEE_{LEA} = 0.22).

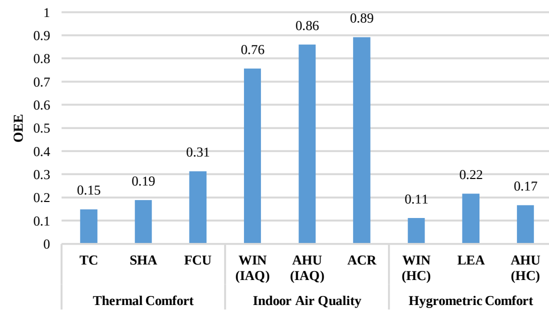

Figure 7. OEE monthly mean values (June 2016).

6. Conclusions

The holonic computing structure, which involves Matlab®/Simulink®, SQL and Revit® development environments, is experienced in a room used as an office. The latter has been used as a proof of concept for further simulations to the whole building. The methodology described in this paper makes it possible to diagnose quickly the causes of building's shortcomings in term of indoor climate comfort and plan future refurbishment. Furthermore, the BIM RM has been experienced as a repository where OEE/OTE effectiveness values of system of systems are stored. Finally, but not least, these values are re-directed to the BIM DM and displayed inside Autodesk® Revit® as element's parameters.

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Identification of relevant project documents to 4D BIM uses for a synchronous collaborative decision support

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Abstract

Currently, the main use of 4D BIM is for visualization of the planned construction process. However, other uses have not yet been fully integrated into construction practices [1]. This paper presents a review of existing context to envisage ways of fostering the implementation of all 4D uses, and also to propose 4D BIM as a support to the decision-making process. Further the research will be completed by survey responses. In order to fully understand and efficiently implement 4D BIM models and methods, we need to develop a precise knowledge of which digital documents should be used and how they influence the decision-making process. This paper studies the convergence between 4D BIM uses and the project digital documents uses. We hypothesize that a construction simulation visualization of the 4D model is a useful source of information and a support for decision-making during a collaborative session. The visualized information and model development level correspond to the decision-making objectives [2].

Keywords: BIM; 4D BIM; 4D BIM use; AEC project managment; collaboration; decision-making.

1. Introduction

Building Information Modeling/Management (BIM) implementation brings changes to many aspects of AEC project development. Along with new benefits and opportunities, AEC professionals are facing new challenges, such as the complexity of data and of work process organization as the project grows. Through the lens of the market view, AEC is dependent on a particular geographical location and related to it demands [3]. In addition to design and construction the current tendency is a frequency increase of additional services demands like facility management [4].

This paper firstly reviews 4D BIM diffusion and BIM project complexity in order to understand the current context and its limits. Secondly, it proposes 4D BIM uses summary, and their relevance to project development phase; in addition, project stakeholders roles on 4D BIM uses are questioned as well; a proposition of relevant complimentary documents to 4D BIM use concludes the section. The last section is dedicated to collaboration and decision-making problematics related to 4D BIM, and to further development methodology for a collective decision-making tool.

2. BIM complexity and 4D BIM diffusion

This section summarizes the of 4D BIM diffusion and French and Luxembourg local context. Also we introduce the BIM project complexity aspect and sociotechnical system.

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2.1. Local BIM adoption and diffusion context for France and Luxembourg

BIM diffusion studies with AEC professionals show their high interest in stronger collaboration or a belief in quality improvements due to BIM. However, more relevant feedback on projects is from firms with high level BIM implementation. Our study interest are France and Luxembourg. Luxembourg is developing a national BIM strategy and BIM execution plan [5], and has a strong initiative and support at the governmental level, where IT-barometer survey shows that firms were not very familiar with BIM (2014), the highest awareness among architects [6].

French digital initiative survey identified three main advantages of BIM perceived by professionals: stakeholders encouragement for stronger exchanges on a project; reduction of design errors; project quality improvement [7]. However, three main perceived disadvantages of BIM were identified as well, namely, the lack of internal skills, software costs, and finally the lack of standardization [7]. Report on French industry says that little more than 10% of firms using BIM regularly [8], and the main concern is about implementation cost and complexity of BIM.

2.2. BIM project complexity, socio-technical system and collaboration

The previously mentioned complexity of BIM encompasses project complexity and organizational complexity [9]. In addition, the multiplicity and ambiguity can also be acknowledged as a part of the information processing approach to task complexity [10]. Figure 1 reviews these influences in detail.

Project complexity	***Organizational complexity***
function, structure, construction method, schedule, size/scale, environment	*agent interactions, design aspects, engineering, management, controls*

Multiplicity + Ambiguity

number of approaches to complete the project + conflicts and decisions to complete the project

Figure 1. Project complexity influences

The complexity of a data organization is created by a number of project documents. 3D BIM model is often a core of the project, and it is linked to all other data which builds a number of dimensions into a holistic model, which covers the whole lifecycle of the project [11] [12]. 3D (x,y,z) + time management models are 4D, and additional to them information on costs stands as 5D. 6D, 7D stand for other resources. Such sophisticated models assure the full collaboration on transition to iBIM [13]. Also, the level of development, provides a progressive complexity increase to the system. Inevitably project document set depends on project type, on development phase and corresponding level of detail. Many BIM standards and guides (80%[14]) offer methods and examples of documents.

With BIM the project stakeholders use a virtual model as a central source of information, design and management support. In this workflow process relies on a sociotechnical system [15][16]. Intelligent models and information management are the system technical core, it is enclosed by social elements: synchronous collaboration, coordinated work practices, institutional and cultural frameworks. The institution has its own intersocial order, which is nevertheless created by the interactions and influences among the institutional professionals [17]. The collaboration improvement is the second most cited benefit after the reduced errors and omissions [18]. These aspects point out the value of collaboration and workflow organization. Also, they are focused on a project quality as a central priority.

2.3. 4D BIM diffusion

During the last two decades the various studies have been conducted and often concluded that 4D BIM adoption rate stays relatively low [18][19][20]. Experiences from pilot projects have already indicated a successful use of 4D simulation for communication on construction sequencing for a number of projects in USA, Finland and China [21]. In Luxembourg a 5-th part of study respondents are familiar with 4D BIM [6]. Global report shows that many contractors have committed to an integration of model with schedule at design and pre-construction phases as one of their top 3 organization leverages (average 29%, 9 largest markets), with 39% in France [18]. 4D BIM in UK survey shows that more of 50% of participants presently use 4D, with a higher level of personal use in organizations with a higher level of maturity; the adoption was an authority or a collective decision [22][23]. Australian research shows a basic level of 4D adoption, the companies tend to delegate 4D,5D-related tasks to external firms [24]. Every context has its own dynamics and specifics, but the global interest and shared problems are similar bonding for all the markets.

A BIM project itself, as a system, is non-linear and adaptive, it is also very interdependent with a significant number of influences involved, thus it must be approached with adaptive management.

3. 4D BIM uses place at digital project development process

4D BIM allies the virtual 3D model of the construction project with schedule, it occurs mostly at the pre-construction phase of development [25]. Projects with 4D BIM are no longer pilot projects but a common way of proceeding due to improved cost control and eliminates errors, whilst making scheduling and coordination more efficient.

3.1. Project lifecycle and time management

AEC project phases depend on a project context, and various phases have different labels and assignments by country, region, project type, contract type, etc. At the large scale, the project starts with the planning, passes through design and construction, and after being delivered has only maintenance interventions. Project risks to be considered during planning and design stages, and managed during construction [26].In addition, time management is introduced early to the project in order to provide proper resource, cost and liability management. At early stage project has an established program, with an already introduced time and cost approximate resources. While the project advances the planning, created by a group of professionals based on their experience, is developed [27]; The planning output would provide documented decisions on work organization. Which are a base for detailed scheduling with calculations, plans, resources and risks attached [27]; scheduling follows at pre-construction phase and becomes a dynamics schedule further during construction (Fig.2).

Figure 2. Time and design management elements of project development

The time management can approached with different methods [20]: Critical Pass Method, Program Evaluation and Review Technique, Linear Scheduling Method, Line of Balance, Last Planner System, Critical Chain Method, Virtual Construction. However, an adaptive dynamic time management may combine these approaches to find the best fit for each section of the project [27]. Program and early planning start at the same time as the concepts and design, once the project shape is defined the time aspect is introduced and developed, and recourses follow it. An efficient dynamic schedule assures review, revision, monitoring, updates and impacts. For a complex BIM project, a single approach would not be efficient, thus early anticipation and a holistic, systematic approach should be implemented.

3.2. Project lifecycle and BIM management

The design development and project management, in the case of BIM project, would be closely related and guided with BIM management. According to the Managing design process roadmap, presented by Gu and London [28], there are steps related to BIM process setups (identification of roles, phases, activities, tools, etc.) preceding the design phase. Also various disciplines have their role in project development (Architecture, Engineering, Cost Management, Quality Control, Time Management, etc.) [27], and one of BIM challenges will be requirement to connect people to project information [29]. Often project is developed by specialists who have not been working together previously, where every firm develops their part of the common project, but since they are separate units, they do not integrate fully into a collaborative framework [4]. Thus, a prepared and project customized organization of the BIM process with a well-adapted framework are essential for efficient design, time and cost, and construction management.

3.3. From 3D to 4D concept

Through the evolution of the project the BIM model evolves as well, gaining new data, new connections, new actors. Since “conceptually 4D CAD represents a type of graphic simulation of a process” [30], it is important to understand what is actually represented in 4D. The dimensions are Time and 3D, and while visualizing the 4D, we still see the 3D and time which are represented through the animation and/or a time diagram, progress line, task list, etc. An added value is a new component created by a relation established between the elements of the 3D model and Tasks, which share and combine assigned data, and technically create their own new concept of a 4D relationship (Table 1.).

Table 1. Dimensions and Data concepts as parts of 4D model

	Time management	3D Model	4D Model	nD
Dimension	Time	*X,Y,Z geometry = 3D*	3D + Time = 4D	4D + N
Data	Task:	*Spatial element:*	*4D relationship:*	nD network
	• ID time • Type time • Start/End/Progress • Resources T • Risks, etc.	• *ID element* • *Type element* • *Resources M* • *Prescriptions*	• *Progress* • *ID (time + element)* • *Type (time + element)* • *Resources (T+M)* • Risks • *Prescriptions*	• Holistic system of elements + time + costs + other project data

3.4. 4D BIM uses

Study of 4D BIM uses follows a more general study of BIM uses, where "BIM Use: A method or strategy of applying Building Information Modeling during a facility's lifecycle to achieve one or more specific objectives." [31].

Guerriero et al. [1] propose following 4D BIM uses: 4D Scheduling, 4D Clash Detection, 4D Safety Management, 4D Site Lay-out & Environment Management, 4D Constructability Management, 4D Monitoring and 4D Visual communication as a core use. One of 4D BIM major benefits is information accessibility and clear visualization - all actors have access to a 3D model and to an attached schedule, to simulations and analysis. All the uses involve stakeholders' expertise and collaboration.

4D BIM uses potential introduction and implementation by project phases and with a corresponding LOD is summarized in Figure.3. The operation and maintenance phase is not in a scope of this research due to the phase specifics and main relevance in a domain of facility management.

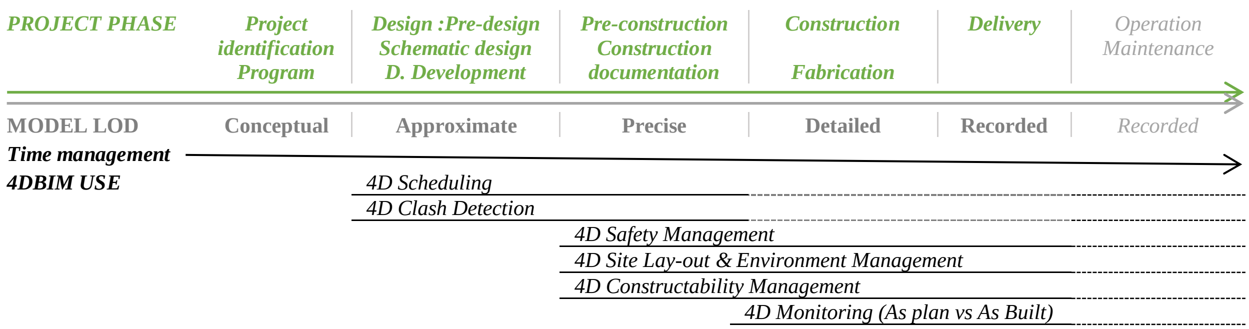

Figure 3. Project phases and model LOD, 4D BIM use potential introduction

4D BIM can be integrated at any phase, when the dimensions and accompanying data are available, sometimes it even may be helpful on negotiation stage. An interesting fact is that survey respondents with less BIM experience tend to identify visualization as a major benefit from BIM, and more experienced respondents tend to find the value in work process organization. In the same way 4D BIM value is perceived as a visualization, however other potential uses have not yet been put in a common practice. It is also often seen as a complementary scheduling instrument [32].

3.5. 4D BIM uses and project stakeholders involvement

The role and involvement of stakeholders are dependent on a project and contract types, on workflow organization. However, a global pattern is predictable to scheme the main workflow components and stakeholder involvement [33]. Table 2 presents a proposition of involvement and influences of stakeholders vis-à-vis 4D BIM uses synthesis.

Stakeholders use 4D BIM and interact with it in various ways, it depends on a project phase. 4D visualization use has a transversal place in project lifecycle, it supports every other use, all the stakeholders benefit from it. The table proposes Responsibility or Participant stakeholders roles, with nuances (responsible validator RV or coordinator RC; participant producer PP, expert PE or reader PR [34]).

For example 4D Scheduling is relevant on a Design and Pre-constriction phases (it is followed by 4D Monitoring during the construction), and involves firstly the project management and a client meeting 3D model creations. Client has RV and PR responsibilities, the process is led by experience of architect and engineers, BIM manager assists to place the methodology and collaboration. Contractor has a secondary role on a design phase 4D scheduling but takes a responsibility of coordination on a pre-construction phase.

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Table 2. 4D BIM uses and Stakeholders operating roles, influences & interactions

Phase / *LOD*	4D BIM use	Role type	Client	Construction manager	BIM manager	Architect	Civil/Structural Engineers	MEP Engineer	Contractor	Safety manager	Workers	Manufactures Suppliers	Building Surveyor	Quantity surveyor	Facility Manager
Design phase *Approximate LOD*	**4D Scheduling**														
	○ Forecast construction phases and sequencing	R	RV		*RC*	RV	RV	RV							
		P		*PE*		PP	PP	PP	*PE*			*PE*		*PE*	
	○ Optimize the construction schedule with the CPM	R			*RC*	RV	RV	RV							
		P	PR	*PE*		PP	PP	PP	*PE*						
	4D Clash Detection														
	○ Detect spatio-temporal conflicts	R			*RC*	RV	RV	RV							
		P		*PE*		PP	PP	PP	*PE*						
	○ Detect static and dynamic conflicts	R			*RC*	RV	RV	RV							
		P		*PE*		PP	PP	PP	*PE*						
Pre-construction phase *Precise LOD* (**4D Visual Communication – Better understanding of the project by all stakeholders**)	**4D Scheduling**														
	○ Forecast construction phases and sequencing	R	*RV*	RC	*RC*	RV	RV	RV	RC						
		P		PP		PP	PP	PP	PP	PR	*PR*	PR	PR	PE	
	○ Optimize the construction schedule with the CPM	R		RC	*RC*	RV	RV	RV	RC						
		P		PP		PE	PE	PE	PP	PR	*PR*	PR	PR	PE	
	4D Clash Detection														
	○ Detect spatio-temporal conflicts	R		PE	*RC*	RV	RV	RV	PP						
		P		PP		PP	PP	PP	PE	*PR*			PE		
	○ Detect static and dynamic conflicts	R		PE	*RC*	RV	RV	RV	PP						
		P		PP		PP	PP	PP	PE	*PR*			PE		
	4D Safety Management														
	○ Analyze structural safety issues	R	*RV*	PE	*RC*	PE	PE	PE	RV	RC	*PR*				
		P		PP		PP	PP	PP	PP	PE					
	○ Identify safety issues (work at heights, moving objects, etc.)	R	*RV*	PE	*RC*	PR	PR	PR	RV	RC	*PR*				
		P		PP		PP	PP	PP	PP	PE		PE			
	4D Constructability Management														
	○ Design temporary works	R		RC	*RC*	PE	PE	PE	RV	*RV*					
		P		PP		PP	PP	PP	PP	*PE*		PE		PE	
	○ Test different construction alternatives	R	*PE*	RC	*RC*	RV	RV	RV	RV	*PE*				PE	
		P		PP		PE	PE	PE	PP						
	○ Optimize interfaces management	R		RC	*RC*	PP	PP	PP	RV	*RV*					
		P		PP					PP	*PE*		PE			
	4D Site Lay-out & Environment Management														
	○ Anticipate environment conflicts (traffic flows, pedestrian, etc.)	R		RC	*RC*	PE	PE	PE	RV					PE	
		P		PP		PP	PP	PP	PP	PR		PE			
	○ Forecast onsite workspace conflicts & subcontracts coordination	R		RC	*RC*	PE	PE	PE	RV						
		P		PP		PP	PP	PP	PP	PR	*PR*	PE			
	○ Adjust the schedule during the construction	R		RC	*PC*	PE	PE	PE	RV						
		P	*PR*	PP		PP	PP	PP	PP		*PR*	PE			
Construction phase *Detailed LOD*	**4D Safety Management**														
	○ Analyze structural safety issues	R	*RV*	PE	*RC*	PP	*PE*	*PE*	*RV*	RC	*PR*				
		P		PP			PP	PP	*PP*	PP					*PR*
	○ Identify safety issues (work at heights, moving objects, etc.)	R	*RV*	PE	*RC*		*PE*	*PE*	*RV*	RC	*PR*				
		P		PP			PP	PP	*PP*	PP					*PR*
	4D Constructability Management														
	○ Design temporary works	R		RC	*RC*	PE	PE	PE	RC	*RV*					
		P		PP		PP	PP	PP	PP	*PE*		PE			*PR*
	○ Test different construction alternatives	R	*PE*	RC	*RC*	PE	PE	PE	RC					PE	
		P		PP		PP	PP	PP	PP	*PE*					
	○ Optimize interfaces management	R		RC	*RC*	PP	PP	PP	RC	RV					
		P		PP					PP	PE		PE			
	4D Site Lay-out & Environment Management														
	○ Anticipate environment conflicts (traffic flows, pedestrian, etc.)	R		RC	*RC*	PP	PP	PP	RC						
		P		PP					PP	PE	PR	PE		PE	*PR*
	○ Forecast onsite workspace conflicts & subcontract coordination	R		RC	*RC*	PP	PP	PP	RC						
		P		PP					PP	PE	PR	PR			
	○ Adjust the schedule during the construction	R		RC	*RC*	PE	PE	PE	RC						
		P	*PR*	PP		PP	PP	PP	PP	PE	PR	PR			
	4D Monitoring			RC											
	○ Give short term goals to construction team	R	RV	RC	*RC*	PE	PE	PE	RC						
		P	PE	PP	*PE*	PP	PP	PP	PP	PE	PR	PR	PE		
	○ Record real progress and compare it to the schedule	R	PC	RC	*RC*	PE	PE	PE	RC						
		P	PE	PP	*PE*	PP	PP	PP	PP	PR	PR	PR	PR	PE	*PR*
	○ Adjust the schedule during the construction	R	PC	RC	RE				RC						
		P	PE	PP	PE	PP	PP	PP	PP	PR	PR	PE	PR		

R : RV – Responsible Validator, RC – Responsible Coordinator, P : PP – Participant Production, PE – Participant Expert, PR – Participant Reader, *Italic – background influence*

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Multiple competences involvement into decision-making on a 4D BIM use must be beneficial in terms of error detection and communication to increase construction efficiency. An important team role is held by construction manager and contractor, who assemble many responsibilities on pre-construction and construction phases. 3D model creators have many responsibilities and influences as well, they have more responsibilities in the beginning of the project, and then have to update their models through all the phases (RV & PP roles). Finally, the client has more of an influence on input data (time and costs related), rather than on construction processes itself.

Once responsibilities and involvement links are summarized, we may look for a project data which would be relevant at the decision-making session, and will offer actors sufficient and complete information on a project (Tab.3). The core of the session support documents is a 4D relationship of 3D model and time management data, in addition to the project stakeholders must have access to other project documents.

Table 3. 4D BIM uses and Project documents for decision-making support

Phase		4D BIM use	4D Model	Complementary project documents
Design phase Approximate LOD	**4D Visual Communication – Better understanding of the project by all stakeholders**	**4D Scheduling** ○ Forecast construction phases and sequencing ○ Optimize the construction schedule with the CPM	**3D models** (Archi, Structural, MEP, Civil) from early design to design development **Time management** program or planning with estimation of time and required construction recourses (general stages)	• State of terrain (plans, permits, environment, soils study) • Program and budget from client • Project volume, specifications (generic numbers, plans) • Project principal stakeholders (generic list) • Construction methodology choice • General requirements on project delivery, program • Calendar events intersecting with construction • Collaboration protocol
		4D Clash Detection ○ Detect spatio-temporal conflicts ○ Detect static and dynamic conflicts		• Models assembled • Rules of conflict detection • Estimations of charges • Collaboration protocol, roles, charts
Pre-construction phase Precise LOD		**4D Scheduling** ○ Forecast construction phases and sequencing ○ Optimize the construction schedule with the CPM	**3D models** (Archi, Structural, MEP, Civic) well established and detailed **Time management** planning with estimation of time and required construction recourses which is transformed into a precise construction scheduling (tasks, elements, dates; construction firm, equipment and material requirements)	• Terrain preparations (plans, permits, environment, soils study) • Project volume, specifications and quantifications • Details (constructing technology techniques, tools, competence) • Plans and technical details of the project • Detailed requirements on project delivery • Project stakeholders roles and interventions limits • Stakeholders calendars and recourses • Collaboration protocol, roles, charts • Economic and management risks and quantifications
		4D Clash Detection ○ Detect spatio-temporal conflicts ○ Detect static and dynamic conflicts		• Rules of conflict detection • Plans and technical details of the project • Construction methodology details • Estimations of charges • Collaboration protocol, roles, charts
		4D Safety Management ○ Analyze structural safety issues ○ Identify safety issues (work at heights, moving objects, etc.) **4D Constructability Management** ○ Design temporary works ○ Test different construction alternatives ○ Optimize interfaces management **4D Site Lay-out & Environment Management** ○ Anticipate environment conflicts (traffic flows, pedestrian, etc.) ○ Forecast onsite workspace conflicts & subcontracts coordination ○ Adjust the schedule during the construction		• Preparations of construction terrain (plans, permits, works) • Project volume, specifications and quantifications • Construction methodology details • Plans and technical details of the project • Project stakeholders roles and interventions limits • Stakeholders calendars and recourses • Collaboration protocol, roles, charts • Security protocols, contracts, insurances, controls • Requirements on project delivery • Safety control protocols • Economic and management risks and quantifications
Construction phase Detailed LOD		**4D Safety Management** ○ Analyze structural safety issues ○ Identify safety issues (work at heights, moving objects, etc.) **4D Constructability Management** ○ Design temporary works ○ Test different construction alternatives ○ Optimize interfaces management **4D Site Lay-out & Environment Management** ○ Anticipate environment conflicts (traffic flows, pedestrian, etc.) ○ Forecast onsite workspace conflicts & subcontract coordination ○ Adjust the schedule during the construction	**3D models** (Archi, Structural, MEP, Civic) initial and ongoing, as-build **Time management** as a precise dynamic construction scheduling (on-going tracking, risks, milestones, logs)	• Project diary (log, reports, photos, scans, exchanges) • Updates on construction terrain with work progress details • Quantifications and supply update • Construction methodology details • Update on human and tools recourses • Project stakeholders roles and interventions limits • Stakeholders calendars and recourses • Collaboration protocol, roles, charts • Security protocols, contracts, insurances, controls • Plans and technical details of the project • Requirements on project delivery • Economic and management risks
		4D Monitoring ○ Give short term goals to construction team ○ Record real progress and compare it to the schedule ○ Adjust the schedule during the construction		• Project diary (log, reports, photos, scans, exchanges) • Requirements lists (e.g. responsible construction firm, materials, equipment) • Collaboration protocols, contracts • Economic and management risks

4. Digital continuum and collective decision-making support research

4.1. 4D BIM and collaborative software interfaces

The complexity increases through a project lifecycle, and it places 3D into a center of exchanges. So it gathers and connects numerous documents, some of them are originally digital and some are digitalized in order to get integrated into BIM process. However, the continuity of digital workflow and BIM workflow is often interrupted at the moment of information extraction in order to prepare a well-corresponding documents to decision-making objective. Thus, to avoid information losses, to optimize work, to avoid redundancy of tasks and to keep the connection to BIM data, it is important to integrate fully collaborative and interoperability offering tools into the equipment set for decision-making.

Table 4. User interface and BIM Viewers for 3D and 4D

	Individual collaborative asynchronous Interface		Collective collaborative synchronous Interface	
BIM software tool type	*3D*	***4D***	*3D*	***4D***
BIM Modelers	•	•		
BIM models Checkers	•	•	*Currently no BIM solution*	
BIM model Viewers	•	***integrated into modelers***		

Software tools are important part of BIM socio-technical system, there are several options and purpose classes: services, catalogs, servers, viewer, modelers, mobile, checkers, management, simulation, communication, publishing, query, utilities [35]. Table 4 compares selected three BIM software tool types (which have direct connection to 3D information visualization and modification), and interface types, in order to understand existing interface limitations concerning collective interaction options. A distant collaboration via cloud server is available with a single user interface. However there is no fully collaborative solution for a synchronous collaboration, in addition, the interoperability data formats have not yet integrated the time dimension into a single model with 3D [33].

Moreover, the 4D model interactions are mostly single-user targeted, thus the multi-user aspect is an important feature to be developed. The digital documents interaction interface must stay digital to avoid incorrect interpretation of the information and data losses, and to offer the best usability to the session participants. Such ease of access and low appropriation time with a tool is offered by natural user interfaces (NUI), we propose to implement a multi-touch collaborative table and wall within a NUI as session equipment. NUI fosters the convergence of 4D uses with project documents and gives an ease of interactions for decision-making.

4.2. Further research for collective decision-making support configuration

Being a part of 4D Collab ANR/FNR research project, this paper participates a global approach (Fig. 3 illustrates methodology steps). To develop a decision-making support configuration and collaboration scenarios, we have already conducted a series of experiments with existing collaboration tools (multi-touch screens and "Shariiing" by Immersion https://www.shariiing.com) with professionals, who worked by design development scenario. The experiments have resumed current limits of collaboration solution and users need for more natural and industry adapted interactions [36]. Next comes the current proposal of relations between project phase and 4D BIM use, and 4D BIM uses relation to project documents, as well as the project stakeholders roles and influences on the uses. Following step will evaluate this summery with a series of AEC professionals interviews, who provide us with real practices and experiences vison. Afterwards, the decision-making tools evaluation and specification will complete a synchronous collaborative tool proposition. Finally, decision-making sessions within a use of 4D, touch table and Shariiing will resume the research.

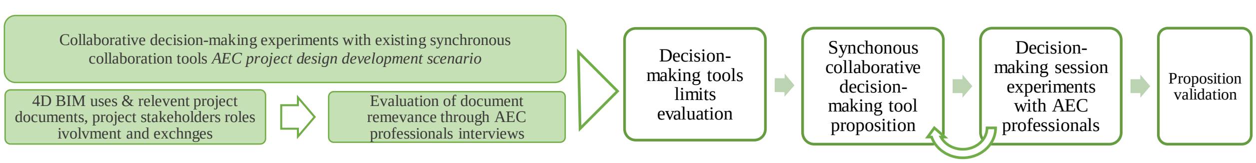

Figure 4. Summary of methodology decision-making support research and development proposition

Conclusion

4D BIM becomes a part of common practices, and besides the improvements of project visualization it offers other uses. 4D BIM uses implementation must be customized to a project development phase. Some of the uses are available already on design phase, but the principal field of implementation is on pre-construction. The uses are not limited to planning activates nor clash detection, but offer an access to construction management and monitoring. Stakeholders roles and responsibilities evolve through the project lifecycle, their role in 4D BIM use and decision-making changes as well. Every decision-making session with a 4D BIM use as an approach has a specific objective and this objective attendance requires a stakeholders' intervention and relevant decision support information on a project. We observe that even with a full information 3D model and time management 4D relation there is still a constant need for additional project documents. The set of these documents alters on the use and on project phase.

The 4D and a set of other digital documents at a decision-making session provide the information support. However the session participants must have an access to relevant interactions with the project information as well in order to keep fluidity of collaboration and better understanding of the project. Therefore, with 4D Collab research project, we continue to progress to develop a configuration for relevant collective synchronous decision-making support, optimized for AEC specific needs and 4D BIM uses in particular.

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Identifying and Analyzing BIM Specialist Roles using a Competency-based Approach

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Abstract

The diffusion of BIM practices and the increasing connotation of BIM contributed to the emergence of several BIM-based specialist roles within the Architectural, Construction, Engineering and Facility Management (AEC-FM) sector. Both the competencies of each specialist role and the potential areas of competency overlap across these roles are not clearly identified in both academic and industry literature. Addressing this gap is important for: creating vocational and tertiary learning opportunities; supporting performance improvement of individuals and potential certification schemes; and defining roles within contract and on projects, and drafting recruitment profiles.
The paper aims to identify the competencies for four key BIM specialist roles – selected based on their citation frequency – and analyze their competency overlap. Three knowledge sieves are used to identify the BIM roles and their competencies: academic literature; national BIM guides and specifications from the UK, US, Norway, and Finland; and job advertisements (i.e. 263 job postings). A BIM competency framework for individuals (i.e. [1]) was adopted while dissecting and collating the roles and responsibilities. The roles and responsibilities were dissected using the framework's competency sets and topics. Social network analysis was used to visualize the competency profile of each roles, the overlap between their competency profiles, and the most prescribed competencies across all roles.
The results included: (1) a competency based profile of four BIM specialist roles, namely the BIM Manager, Information Manager, BIM Coordinator, BIM Technician; (2) an identification of the competency overlap between each pair of roles and across all roles; and (3) an identification of the competency sets and topics that are required by most roles.

Keywords: BIM; Competency; BIM Coordinator; BIM Manager; Information Manager; BIM Technician; Social Network

1. Introduction

Building Information Modelling (BIM) is not only changing the way assets are designed constructed and operated, but it is also contributing to the creation of new roles and the alteration of existing ones. BIM is the current expression of digital innovation within the construction sector [2]. Despite the significant impact of BIM concepts and workflows on individuals across all disciplines (planning, design, engineering, construction, facility maintenance, etc.), and the emergence of BIM-specialist roles (e.g. Information Manager, BIM Coordinator, BIM Manager, etc.), 'people-focused' research questions remain relatively less investigated. Generally, aspects of social and political systems, such the evolution of existing and new specialist roles and adoption rates, lag behind the technical development for most innovations. However, with BIM the evolution of new BIM-based roles has rapidly expanded as evidenced by the proliferation of new BIM-based specialist roles. New BIM-based roles are witnessed in BIM policy documents (e.g. standards, guides, and protocols), the academic literature, and specialist recruitment adverts. However, clarity about these roles and their competencies is lacking [3]. Both industry and academia are

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seeking to understand the communalities and differences between these proliferating BIM-specialist roles [4]. Competency refers to an individual's 'ability' to perform a specific task or deliver a measurable outcome [1]. Many studies have found relationships between the competency of team members and the overall performance of organizations [5, 6].

First, this paper will identify the four main BIM specialist roles that will be selected based on their citation frequency across industry standards, job advertisements and academic literature. Second, the paper will map the competencies of these roles by dissecting their role descriptions from the three identified sources: academic literature; national BIM guides and specifications from then UK, US, Norway, and Finland; and job advertisements (i.e. 263 job postings). Finally, the paper will establish a competency profile for each role and conduct a cross-role analysis to investigate the competency communalities and differences between the four identified roles.

2. Literature review

Several BIM specialist roles have emerged with the increasing adoption of BIM across the AEC-FM. These roles are witnessed in policy documents such as BIM guides, standards and protocols; job advertisements; and relentless discussions on social media. Mathews (2015) identified three roles (BIM Technician, BIM Coordinator and BIM Manager) and argued that there is still a confusion within the industry in relation to the meaning and interpretation of these titles [7]. Joseph (2011) emphasize the difficulties human resource department within the AEC-FM sector are facing in understanding these roles. A few studies by academia, industry and policy makers have attempted to clarify these specialist BIM roles from different standpoints. Existing studies can be classified into three categories: 1. Studies proposing framework that focus on either competency (i.e. [1]) or learning outcomes (e.g. [8]); studies classifying roles and analyzing their role definitions using available BIM guides (e.g. [9]); and studies parsing and analyzing job descriptions from job postings [4, 10, 11]. This section will review the main work in each of these categories.

Within the first category of studies, Succar et al. (2013) proposed an integrated approach for the assessment, acquisition and application BIM competencies [1]. A fundamental part of this approach is the identification and classification of competencies. A multi-level taxonomy of BIM competencies with three competency tiers (Core Competencies; Domain Competencies; and Execution Competencies) and an extensive list of competency sets (e.g. Functional, Technical, etc.), competency topics (e.g. collaboration, facility management, etc.) and competency items (e.g. develop model ownership protocols with other project participants at the start of a collaborative BIM projects) was proposed. The identification of the competencies within this approach is holistic as it considers all ways of competency manifestations including competency as an ability, an activity, and an outcome.

In the United Kingdom, the BIM Task Group, developed a preliminary 'BIM Learning Outcomes Framework' outlining three tiers or areas of individual BIM competencies as learning outcomes [12]. These included:

- Strategic level: Strategic learning outcomes focusses on e.g. the understanding of the BIM value proposition, the Government requirements, industry context of BIM adoption, impact to client and relationships, development of investment models, among many others;
- Management level: Management learning outcomes include a set of learning outcomes under key heading such as acquiring internal resources, Developing Organizational Business Plan, Managing external requirements, managing people, Managing processes and Managing technical infrastructure; and
- Technical level: Technical learning outcomes cover the capability of individuals to identify project requirements, assess contextual data and their impact of project development, develop design solutions, manage design information, implement procurement process, manage project handover and facilities information, etc.

This approach has some shortcomings, when compared to Succar et al.'s (2013) approach. First, it does not consider all of, and distinguish between, the three types of competency manifestations (i.e. ability, activity and outcome), which are important for educators and learners (e.g. structure their educational and learning offering) and practitioners and human resource planning (e.g. to develop targeted learning opportunities and role descriptions for recruitment purpose). Second, its structure has limited layered tiers to sufficiently guide the process of competency identification and assessment.

Within the second category, Davies et al. (2017) analyzed the definitions of BIM specialist roles from the BIM guides of several countries. The findings showed (1) a lack of clarity in the definition of client-side roles in the BIM process; (2) overlapping use of similar role titles to describe different functions within BIM project teams; and (3) lack of clarify in relation to the distinction between project-based roles versus organizational roles [9].

Within the third category, Barison and Santos (2011) analyzed 31 online job postings and identified eight roles including BIM manager, BIM modeler, BIM trainer, BIM director, BIM technician, BIM consultant, BIM marketing manager, and BIM software support engineer [11]. However, the competency identification was performed for BIM managers only under six competency topics including: aptitude, education, experience, skill and ability, knowledge, and attitude. Uhm et al. (2017) parsed 242 online job postings from three countries to identify the BIM specialise roles and their competencies. Following the parsing and mining of the data from the online job postings, the research adopted the O*NET (the Occupational Information Network) for the classification of competencies. The O*NET is a generic – not BIM specific – classification of worker competencies, requirements, and resources. This study identified eight BIM specialist roles (e.g. BIM project manager, director, BIM manager, BIM coordinator, BIM designer, senior architect, BIM mechanical, electrical, and plumbing (MEP) coordinator, and BIM technician) [4]. The identified competency related terms were then categorized using the O*NET classification into 43 competency elements covering essential, common, and job-specific competencies. The results represent a useful inventory of competencies. However, two shortcomings of this study are: (1) using a generic and not specialized competency framework affect the clarity of competency classification; and (2) using a classification framework to classify the outputs is less effective than using it for the beginning to guide the mining and classification process of role competencies. The proposed study will overcome these limitations through the adoption of a specialized BIM competency framework (i.e. [1]) from the start and throughout all the stages of the research process.

3. Methodology

The research methodology is illustrated in Fig. 1. The first is the identification of an adequate competency framework that can guide the research process by providing a clear BIM-specific competency taxonomy for individuals. The framework's taxonomy can be used for developing the codes for the thematic analysis and for dissecting the role description of specialist BIM roles. The specialist BIM roles were then identified from across three knowledge sieves including academic literature, policy documents (e.g. BIM guides, protocols and standards), and job postings. The study focused on the three top roles that were selected based on their cumulative citation frequency across the three knowledge sieves. Using the competency sets and competency topics from the integrated competency framework of Succar (2013) as codes for the thematic analysis of roles, all descriptions of roles were dissected and included in an integrated competency table for all roles. Finally, once the competency profile for each role has been created, social network analysis was used to perform a cross-role analysis of BIM specialist roles. The software tool used to for network analysis and visualization is Gephi. The Gephi's algorithm used for spatializing the network is FORCE ATLAS2 in which Nodes repulse each other like charged particles, while edges attract their nodes, like springs (Jacomy et al., 2014).

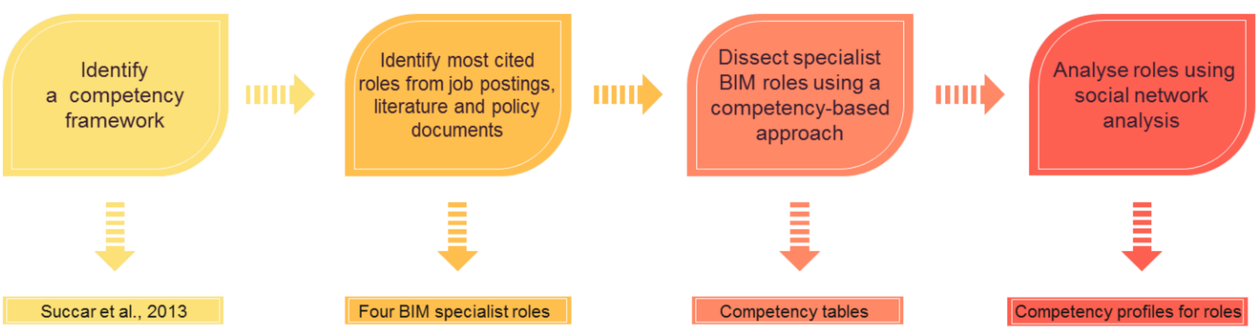

Fig. 1. Research methodology for the identification and analysis of competencies of BIM specialist roles

4. Findings

The roles were identified in policy documents originated from the UK (International BIM implementation guide RICS guidance note; PAS 1192 -2; and CIC BIM Protocol), the US (National BIM Standard-United States®; LACCD BIM Standards for design-bid build Projects; and VA BIM GUIDE v1.0), Finland (Senate Properties BIM Guide) and Norway (Statsbygg BIM Manual 1.2.1); five academic and industry papers (i.e. [4, 7, 8, 10, 14]), and 263 job postings. Table 1 shows the identified 14 roles and their total frequency of citation across each of the three source types. The three roles that were cited most across all the three sources types are: the BIM Coordinator, the BIM Manager, the BIM Technician, and the Information Manager. The competency analysis exercise will focus on these four roles. The divide between policy documents and job postings in relation to the role is remarkable: for example, despite most of the job advertisement web sites (.co.uk, totaljobs.com; jobsite.co.uk; bd4jobs.com; and adzuna.com.uk) are UK-based and the ‘Information Manager’ is the role prescribed in the UK BIM policy documents, there are very few job postings seeking Information Managers. This early observation strengthens the proposition made in the beginning of this paper about the need for understanding communalities and differences between these roles.

Table 1. Identified BIM specialist roles and their frequency of citation across the three sources.

BIM specialist Role	Job postings	Academic and industry literature	Policy documents
BIM Coordinator	90	3	2
BIM Manager	66	5	
BIM Technician	59	3	2
BIM Consultant	14		
BIM Analyst	7		
BIM Modeler	5	2	
BIM Designer	4		
BIM Product Manager	4		
Head of BIM	4		
BIM Champion	3		
Information Manager	2		3
BIM Implementation Manager	2		
BIM Leader	2		
BIM Facilitator	1		1

Following the identification of the BIM specialist roles, an extensive thematic analysis of their role description was conducted across all the three document types. The thematic analysis was guided by the competency sets and competency topics from Succar et al. (2013) and was executed according to the six-step process proposed by Braun and Clarke (2006) [18]. Table 2 includes all the competency sets and topics that were encountered for the BIM specialist roles across the three document types. Table 3 is an extract of the table that shows the thematic analysis performed on the policy documents. The same approach was used to analyze each BIM specialist role within the source in which was identified. As a result of this process, an integrated competency table that contains the list of competencies for each role was formed. Table 2 shows that BIM specialist roles are characterized by eight competency sets and 31 competency topics. The practical implication of these results is in informing the on-going debate about BIM specialist roles and the extent to which BIM adoption affects industry roles (new specialist BIM roles versus existing pre-BIM role). For the example, the main BIM protocols (i.e. CIC BIM Protocol) and standards (i.e. PAS192-2 2013) supporting the UK BIM Level 2 introduce several new BIM specialist roles including the ‘Information Manager’ who should present in every in every BIM-enabled project. Conversely, some guides such as the Associated General Contractors of America’s US Guide to BIM affirms that "BIM does not change the fundamental roles and responsibilities of project participants” [15 cited in 9], and that “the effective use of BIM does not require that the project participants assume any roles other than their traditional ones” [15]. Discussions on social media seem to assume a middle position between the former two opposing views and claim that the BIM specialist roles are temporary and will exist until they are absorbed in traditional or existing professional roles. The identified competency table could provide a tangible means for this debate by helping the discussion from a broad level (i.e. role level) to a more granular level (i.e. competency level)

Table 2. List of competency sets and topics identified for the four roles across three source types

Competency Set (Code)	Competency Topic (Code)	Competency Set (Code)	Competency Topic (Code)
Managerial (M)	Leadership (M02) Strategic Planning (M03) Organizational Management (M04) Business Development & Client Management (M05)	**Technical (T)**	Hardware and Equipment (T03) Modelling (T04) Documentation (T05) Presentation and Animation (T06) Document Management (T08)
Administrative (A)	Administration, Policies & Procedures (A01) Marketing (A05) Contract Management (A07) Quality Management (A09)	**Implementation (I)**	Implementation Fundamentals (I01) Library Management (I03) Technical Training (I05) Guides and Manuals (I07)
Functional (F)	Functional Basic (F01) Collaboration (F02) Facilitation (F03) Project Management (F04) Team and Workflow Management (F05)	**Supportive (S)**	General IT Support (S01) Data and Network Support (S02) Software Support (S05)
Operational (O)	Simulating & Quantifying (O04) Constructing and Fabricating (O05) Linking and Extending (O08)	**Research & Development (R&D)**	General Research & Development (R01) Teaching and Coaching (R03) Knowledge Management & Engineering (R04) Change Management (R05)

Table 3. An extract showing the thematic analysis of specialized BIM roles identified in policy documents

Competency Set (Code)	Competency Topic (Code)	Descriptions	BIM Manager	Information Manager	Standard Document
Managerial (M)	Leadership (M02)	Guiding organization to improve the process of implementing BIM	●		NBIMS
	Strategic Planning (M03)	Leading BIM strategic planning	●		LACCD, VA BIM GUIDE, SENATE
	Organizational Management (M04)	Managing resistance to change	●		NBIMS
Administrative (A)	Administration, Policies & Procedures (A01)	Understanding legal implication of BIM	●		RICS
		Develop and maintain BIM procedure and protocol (BEP, EIR, scope, strategies etc.)	●	●	RICS, CIC

4.1. Cross-role analysis of BIM specialist roles

The academic and industry literature have reported challenges in relation to the distinction between the different BIM specialist roles. The cross-role analysis aims to analyze the extent of the competency overlap between the four identified roles. In particular, it will analyze the competency overlap between the BIM Manager role and the Information Manager role, the two roles that are often subject to contention. The cross-role analysis will also identify the communalities including the most required competencies across all roles.

To analyse the competency overlap between the roles, the integrated dataset of the competencies for all roles - built from the three document types - was spatialized in Gephi using a force-directed algorithm called ‘ForceAtlas2’. This algorithm enable nodes repulse each other like magnets, while edges attract their nodes, like springs. The result

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is a visual network in which structural proximities are reflected into visual proximities facilitating the analysis of the social network. The competency visual network for the four specialist BIM roles is illustrated in Fig. 2a. The findings from this network indicate:

- The BIM Coordinator is the role that is linked to the highest number of competency topics followed in a descending order by the BIM Manager, the Information Manager, and the BIM Technician;
- The majority of competency topics are shared by more than one BIM specialist roles. This establishes evidence for the argument found in the literature about the general challenge of distinguishing between the BIM specialist roles;
- Surprisingly there is a structural proximity between the roles of the Information Manager and the BIM Technician. This can be explained by the fact that these two roles are mainly project-oriented, unlike the BIM coordinator and the BIM Manager that often amalgamate competencies required for both organisational and project activities. This finding also echoes the findings of [9] about the lack of clarify between project-oriented and organisation-focussed BIM specialist roles.

The cross-analysis also identified the most required competencies across roles. The centrality in-degree analysis which measures the number of edges running into each node (competency node) was used. The larger and the darker the node, the higher the number of roles linked to the competency items/topics (Fig. 2b).

For the four selected roles, the most required competency items/topics are:

- A01-1 (developing and maintaining BIM procedures and protocols) which is under the Administration, Policies & Procedures (A01) competency topic of the Administration (A) competency set; and
- O08-1 (synchronising models and data) which is under the Linking and Extending (O08) competency topic of the Operational competency set.

The subsequent most required competency items/topics are related to the Functional and the Technical competency sets. These are F04-1 (Managing the delivery of BIM projects), T06-1 (Generating full 4D & 5D model), and T08-1 (Administrating model and document sharing and publication).

Finally, this section analyses the communalities and differences between the BIM Manager role and the Information Manager role. This analysis is important to explore given the divide identified in relation to these two roles between policy documents and job postings. The results show that there is a significant overlap in the competencies between the two roles. This overlap includes competency topic spread across several competency topics including: Administration, Policies & Procedures (A01); Collaboration (F02); Project Management (F04); Linking and Extending (O08), and Document Management (T08). Communalities and differences in the competencies between roles is included in the discussion and conclusion section.

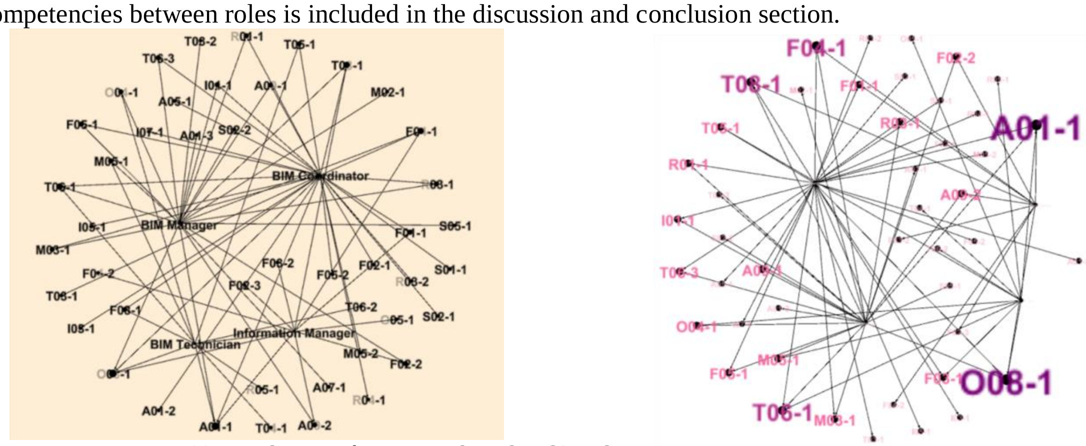

Fig. 2. (a) Spatialisation of BIM specialist roles; (b) In-degree centrality of competencies of all BIM specialist roles

4.2. Profile summary of each role

Following the above analysis, the competency for each role were gathered from all three source types to create a profile summary for each of the selected roles (Fig. 4). The description of each role – with the exception of the Information Manager role – amalgamates project-focused competencies (e.g. managing the information received from different parties) within organization-focused competencies (e.g. managing resistance to change). This may have resulted from merging into the role competencies from different sources (job postings, literature) including disparate policy documents (guides, standards, and protocols) that could be either organization or project focused. Indeed, the literature provide evidence that policy documents include organizational BIM roles and activities in project-level guides and standards and urge for a division between the two reduce ambiguity and uncertainty [9]. Exempt from this issue is the Information Manager whose role description is mostly project-oriented.

Fig. 2. A role profile summary for the BIM four specialist roles

5. Discussions and Conclusions

Conflict is evident in the academic literature, professional forums and policy documents about the impact of BIM on professional roles and the clarity of BIM specialist roles. On the one hand, some associations (e.g. Associated General Contractors of America) argues that BIM does not change the fundamental roles and responsibilities of project participants [15]. On the other hand, some scholars [e.g. 16] asserts that BIM will change and affect all roles in a project. An intermediate position by Gu and London (2010) claim that BIM will make some role obsolete and create new roles. This paper addressed the challenge related to the clarity of the definitions of BIM specialist roles and the demarcation between the roles. This paper contributes to this on-going discussion by approaching this challenge from a competency angle. The paper adopted an integrated competency framework with structured competency sets and topic to guide the research process. In particular, the paper analysed four specialist BIM roles (i.e., BIM Manager, Information Manager, BIM Coordinator, BIM Technician); identified their competency profile and the most prescribed competencies topics and items; and analysed their competency communalities and differences. The highest number of competency topics and items were linked to the BIM Coordinator role followed by the BIM manager, the Information Manager, and the BIM technician, respectively. Competency items that were found to be linked to three or four roles belonged to the Technical, Functional, Operational, and Administrative set. All roles, except the Information Manager role, amalgamated competencies that are relevant to project-environment with competencies focussed on organisational environment. It is widely acknowledged as being a project-specific role that is not permanent and/or exclusive to one player within the project supply chain. Different players can assume it at different project stages as the project progresses. The exclusion of the Information Manager from this challenge may be explained by the influence of noteworthy policy documents and the leading role of policy makers in introducing and defining the role. This suggests a potential relationship between the role played by the policy makers and policy documents when they prescribe the role’s label and definition and its understanding by industry. However, despite the Information Manager is the most notable role prescribed in the UK’s policy documents, job postings are hardly seeking this role even when these job posting’s company and web page are based in the UK. This may indicate that the direction and changes of role labels occur as the inevitable consequence of the interplay of market forces (e.g. position of BIM policy documents about roles and labels versus commercial market position). The identification and analysis of these dynamics in future research is interesting.

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Mobile-based 3D Reconstruction of Building Environment

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Abstract

On-time environment perception of construction site is considered as an indispensable step for project management. Real-time tracking and feedback the status of construction facilitate progress monitoring and quality control. Image-based modelling and RGB-D mapping are considered as a non-invasive and low-cost technology which are always used for data collection and reconstruction of as-built building environments. Recently, the arrival of reliable and efficient computational of mobile terminal service has given us an opportunity to develop a mobile-based spatial data reconstruction system. Considering the capacity of processing and real-time performance on a mobile device, Oriented FAST and Rotated BRIEF (ORB) features are extracted. The ORB features are used for subsequent procedures, including tracking, mapping, relocalization and loop closing. In contrast to image-based off-line modelling, a real time Simultaneous Localization and Mapping (SLAM) algorithm was utilized to estimate the camera trajectory while reconstruction the building environment. Keyframes selection strategy was proposed to reduce the redundant images and generate a robust and trackable sparse point clouds. The keyframes and sparse point clouds are transferred to a computer for generating dense point clouds, grid reconstruction and texture synthesis. Finally, the reconstruction result will be transferred back to mobile and can be displayed directly on a mobile device. As an initial effort, this paper investigated the potential of live reconstruction of indoor building scenes on an android mobile device. Taking the advantages of operable and portable, the system can be used for data acquisition of as-built information by construction workers.

Keywords: 3D Reconstruction, As-built Data Acquisition, Mobile Terminal, Monocular SLAM, Relocalization.

1. Introduction

Three-dimensional information help mitigate the conflict in a construction project where multiple participants are involved [1]. Rather than tedious documents, the visualization of information such as color, texture, shape can be extracted from images/videos that is conducive to communication and decisions-making for stakeholders. Non-intrusive reconstruction of environment technology was widespread used to acquire 'as-built' spatial information. The 'as-built' information referred to the representation of construction status that can be used for building inspection [2], construction assets tracking [3] and building refurbishment [4].

There are three automated non-contact spatial technologies: (1) Laser scanning technology which collected 3D coordinate of massive points with high accuracy by Terrestrial Laser Scanner. But, the application limited by its high cost, large file sizes and extra specialized operators [5]. (2) Range image-based technology, which using a Red Green Blue and Depth (RGB-D) camera to acquire depth images, and then generate dense point clouds by fusing depth map with multiple viewpoints. While the range camera has the advantage of reconstructing moving objects for equipment and material management, its accuracy is inversely related to the scanning range [6]. Meanwhile, range camera is

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sensitive to illumination that result in cannot be accommodated to outdoor environment. (3) Image-based technology which converted 2D continuous photographs into a point cloud model by estimating camera exterior parameters. Structure from Motion (SfM) algorithm was widely used to recover the camera motion and the structure of the scene [7]. However, the SFM triangulation is constrained to the requirement of at least three interrelated images and overlaps between sequential images. As a result, an amount of redundant images are stored that burden computational cost. Moreover, image-based and RGB-D camera based technology are offline data acquiring pattern that is unable to real time predict the performance of modeling. The corollary in this instance is that the invalid data will cause reconstruction process failure.

Technological advancements in field such as robotics, optics and computer vision have been development in real time visual 3D modeling manipulation. Visual Odometry (VO) algorithm [8] was introduced to estimate the trajectory of a camera traversed through its environment. The system, which updates the new camera post with new image adding, combined with Inertial Measurement Unit (IMU) to obtain reconstruction model on a Project Tango Tablet [9]. But the track of features is liable to lose when the occlusion occurs, that obtained 3D information will be discarded.

Visual Simultaneous Localization and Mapping (VSLAM) [10] used vision information to estimate camera motion, and then stored 3D information in the corresponding map. Some references regarded VSLAM as online version of SFM. Scale Invariant Feature Transform (SIFT) and Speeded Up Robust Features (SURF) features [11] were common used for correspondences matching and the structure of the scene recovering. The features are robust to image scaling and rotation, and good invariance to changes in viewpoint and illumination However, SIFT/SURT-SLAM was limited to its large amounts of computational, and unable to operate in real-time without GPU acceleration. The corollary in this instance is that SIFT/SURT feature was not suitable for building sparse map on a mobile device.

In consideration of aforementioned limitations, an ORB-SLAM method is proposed to generate real time sparse point clouds on a hand-hold mobile device. The strategy of selecting and culling keyframes is implemented to avoid unnecessary redundancy. In each keyframe, ORB features are extracted in each keyframe and the matched features are visualized to ensure the validity of triangulation for online modelling. The remainder of this paper is presented in the follow structure. In section 2, a mobile-based algorithms for 3D sparse map generation and optimization is presented. The keyframes and map information are then transmitted to computer to generate 3D grid model in Section 3. Finally, the contribution of the study is highlighted and future work is anticipated.

2. ORB-SLAM operated on mobile device

To achieve the goal of 3D reconstruction building environment, a smartphone with monocular is leveraged to acquire interactive incremental frames. In this instance, tracking and local mapping steps run on the mobile device. Subsequently, the generated sparse point clouds are transformed to personal computer to ensure the computational efficiency. Followed by the dense point clouds, gird reconstruction and texture synthesis steps. The following subsections describe the workflow in detail. Fig. 1 illustrated all the steps refer to the system.

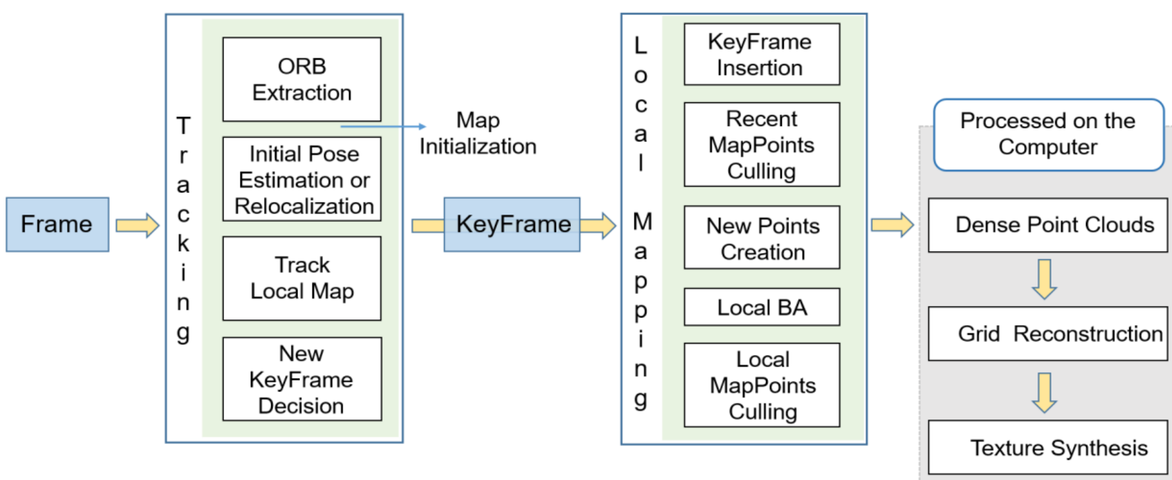

Fig. 1. the workflow for mobile-based reconstruction system.

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2.1. Tracking

The process of initialization, tracking and keyframes decision are interpreted in this section. The ORB features are extracted from keyframes for recovering the initial relative camera pose. To ensure consistency of tracking, the bag of words strategy is proposed to speed up correspondences matching in case of tracking lost situation. Meanwhile, the keyframes are selected for the following mapping.

2.1.1. ORB feature extraction

Feature-based Simultaneous Localization and Mapping (SLAM) represents a branch which considering both camera trajectory estimation and environment reconstruction. Oriented FAST and Rotated BRIEF (ORB) feature [12], which is binary feature has good invariance to rotation and scale, built on the FAST key-point detector algorithm [13] and developed BRIEF feature descriptors algorithm [14]. Compared to the SIFT/SURF, ORB features have been greatly improved in extraction speed and efficiency, which allows real-time performance on the mobile device. Moreover, the same features can be used for all subsequent tasks: tracking, local mapping and dense reconstruction.

2.1.2. Initial pose estimation or relocalization

Extracting SFIT or SURF features was expensive in terms of computational time. While BRIEF descriptors take the advantage of fast features matching and comparing which accommodated for operated on the smart phone. The BRIEF descriptor is a binary vector of a square patch around each FAST key point. To find the initial correspondence, extracting features x_1 in the current frame F_1, and searching for matches $x_1 \leftrightarrow x_1'$ in the reference frame F_1'. Computing the Hamming distance between two descriptors of bits and find the correspondence points which with the nearest distance. Considering consistency with previous matches, the camera pose and a guided search of map was predicted based on the last frame. In the case of without enough matching points, a wider search around their position is implemented and the corresponding pose is optimized.

Noteworthy, sudden motions or motion blur is inevitable situation in the process of modelling operations by foremen on the construction site. That would result in map tracking lost and geometric information loss. To overcome the situation, Bag of Words (BoW) [15] is used for matching and place recognition efficiently. A vocabulary tree was built to discretize a binary descriptor space and to speed up geometrical verification. Each image is converted into the bag of words vector and clustered different levels of nodes in the vocabulary tree. The features of images and their associated nodes are stored in the direct index. At the same time, the weight of words in the images are stored in the inverse index. In the context of tracking lost, when adding a new keyframe $I_{f'}$ into the database. The database query to retrieve similar image I_f to the given one. To obtain the correspondences with the highest probability, I_f is searched in the direct index that their features that belongs to the same level nodes. The constraint condition is to speed up the search and matching computation. The RANSAC is performed to calculate a fundamental matrix between I_f and $I_{f'}$, then the camera pose can be found by the PnP (Perspective-n-Point) algorithm [16].

2.1.3. Track local map

After enough matching points are found，8 pair of matching points are selected as a group respectively inside a RANSAC scheme. To reduce computation cost, parallel computing two models: a homography H and a foundation matrix F. The re-projection error and the chi-square distribution are computing a score for each model, record as S_H, S_F. Discarding outliner region and retaining the homograghy and fundamental matrix with the highest score. Calculated the percentage of scores as shown in Eq.(1):

$$R_H = S_H / S_H + S_F \quad (1)$$

If $R_H > 0.45$, which indicates the scene is planar and low parallax, the homography is selected. Otherwise, the fundamental matrix is selected to recover the initial relative camera pose and map.

2.1.4. New keyframe decision

The expansion of scanning range and accumulation of scanning time that resulting in large image file and complexity computation. Considering the extra cost of massive redundant information which indwelled in similar continuous images. Features are extracted from key-frames instead of every frame that reduced the volume of image file and speeded up data transmission. Obtaining high frame-rates allows to optimize camera tracking and mapping of SLAM system in parallel threads on mobile devices.

To ensure robust relocalization and tracking, and the new keyframe can be inserted as soon as possible. A minimum visual change strategy is imposed. The inserted keyframe should meets the following conditions:

- After the last global Relocalization, more than 20 frames have passed;
- After last keyframe insertion, more than 20 frames have passed;
- At least 50 points in current frame tracks;
- Current frame tracks less than 90% points than feature points in last keyframe.

2.2. Local mapping

As the camera moves with the scanning trajectory, new keyframes are added to the system to grow the map. If a match has been found, a new map point is triangulated and inserted into the map. The strategy of recent map point culling is to ensure the map contain fewer outliners. The point which retained in the map meet the conditions of trackable and not wrongly triangulated. That indicated more than 25 percent of point in the frame are visible and the map point can be observed from at least three keyframes. A covisibility graph [17] is used for real time operating in large scale environment which accommodated to construction site. ORB features are triangulated, and to create new map points from collected keyframes in the covisibility graph.

The local bundle adjustment (BA) is implemented to optimize the surrounding of the features and the camera pose. That is ensure all the keyframes connected to the covisibility graph and all the map points can be seen in their keyframes. Considering the memory space on the smartphone is limited, some keyframes are deleted to avoid unbounded growing. For the keyframes in connected keyframes set, which 90 percent of map points can be seen in more than two keyframes in a fixed scale regarded as the redundant keyframes. The process allows to discard redundant keyframes and maintain a compact reconstruction.

3. Experiment implement and results

An experiment is used to demonstrated the ability to reconstruct building environment with the mobile device acquire ‘as-built’ spatial information. The real time tracking and local mapping steps are performed on a mobile device

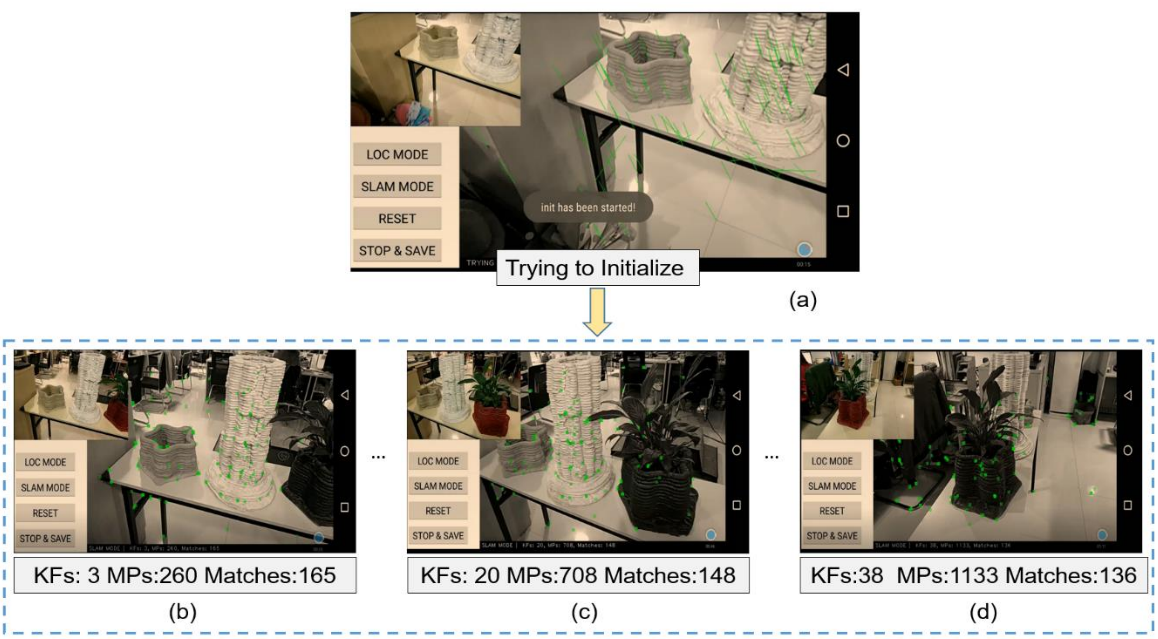

Fig. 2 the real time initialization and keyframes insertion process on the mobile device with a monocular camera. The result benchmarked on the smartphone with 2.45/1.90 GHz MAM8998 CPU, 6GB RAM, based on Android 7.1 system. The ORB-SALM process of generating keyframes and sparse point clouds data can be seen in Fig. 2. As shown in Fig. 2a, the system trying to estimate the initial camera pose. Once the initialization is completed, the matched points can be found in each keyframe and are denoted in Green Square in Fig. 2b, 2c and 2d. It also shows the current number of keyframe and local map points, respectively represented as ‘KFs’ and ‘MPs’. With the moving of the camera, more keyframes are inserted and new point are triangulated to update the local map points. To ensure the robustness of system and reduce the computational cost, the visualization of sparse point clouds are closed.

A total of 56 keyframes at resolutions of 780*480 pixels and covisibility information are transformed to a computer to enhance computational efficiency. Then, the subsequent steps are performed on a server equipped with a with a 3.10 GHz Intel(R) Xeon(R) E3-1535M CPU, a NVIDIA Quadro P5000 GPU and 64G RAM. Fig. 3 illustrates the process of generating a 3D gird model. A depth propagation algorithm, which is better than conventional PMVS algorithm, is used to transform the sparse point clouds (Fig. 3a) to a dense point clouds, as shown in Fig. 3b. After creating a dense model, *Delaunay* triangulations is used to generate grid triangulations. A graph-cut optimization algorithm is proposed to label each tetrahedron and the gird is extracted from inside and outside the boundary. In view of hallucinations, a small amount of noise is added to eliminate the interference and the result is presented in Fig. 3c. As shown in Fig. 3d, a picture patch of an object is projected back on to the corresponding surface. The pixel of each image patch is assigned a corresponding weight value to improve the clarity for texture synthesis.

For convenience of inspection the reconstruction model on construction site, the 3D grid model is transferred back to the mobile device. Where, Fig. 4 stand for the result of 3D gird reconstruction. In Fig. 4a, the reconstruction result is displayed on a MeshLab platform on the computer. A gird models is displayed via 3D Model Viewer App which is operated on the smartphone as shown in Fig. 4b. It can be seen in Fig. 4b, the performance of gird model on the smartphone can reflect the 3D modelling situation on the computer.

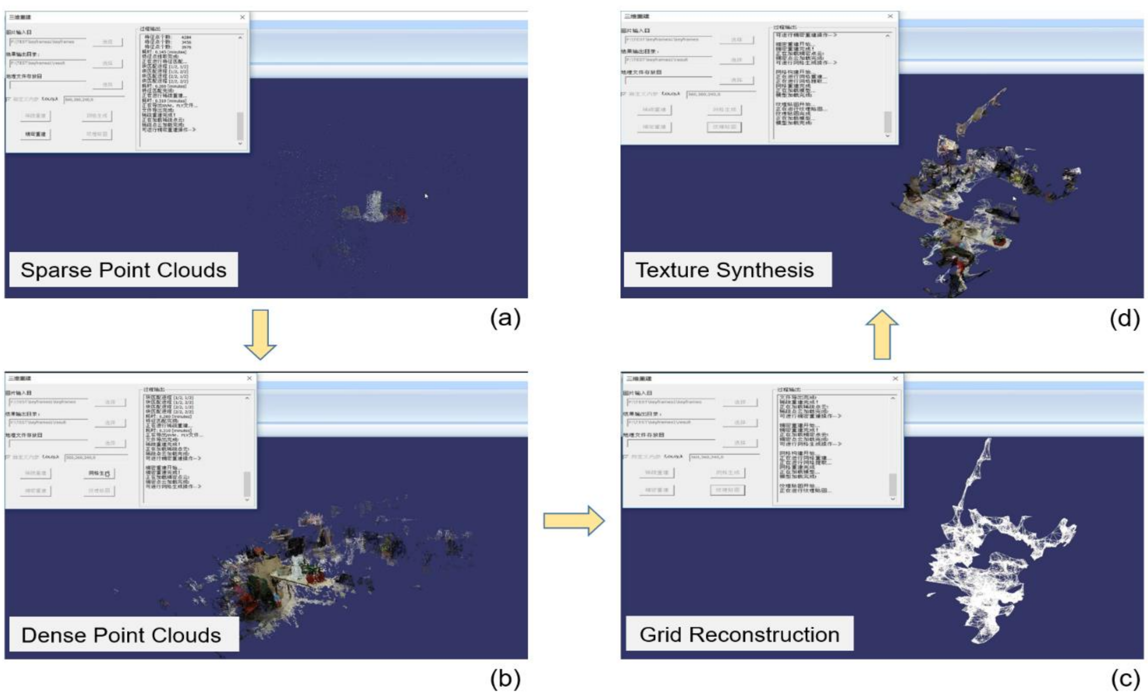

Fig. 3 the process of generating a 3D gird model on a computer

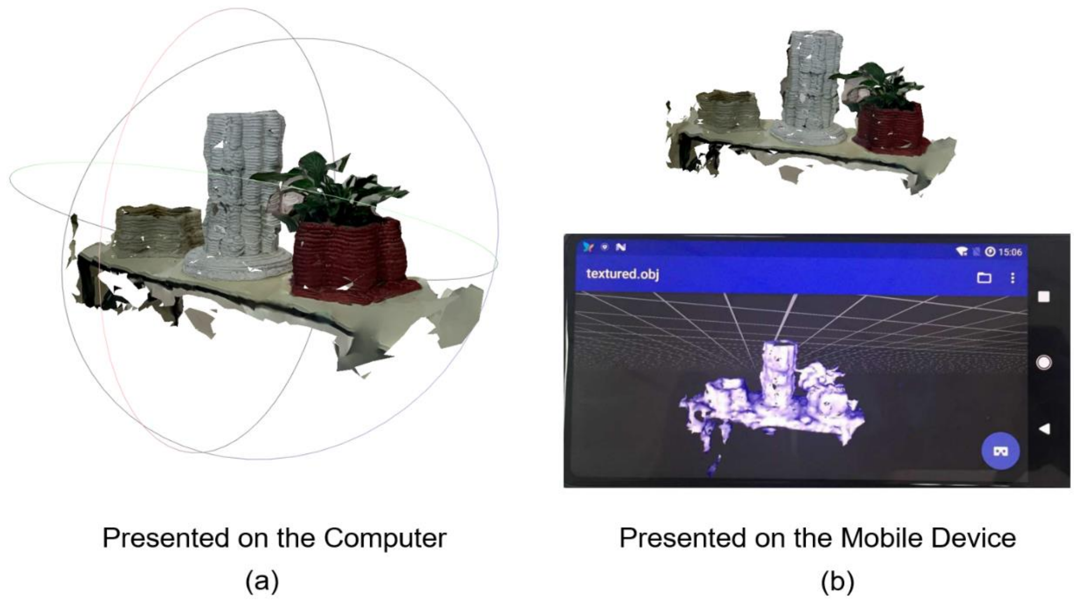

Fig. 4 the results of 3D gird model is presented on a computer screen and a mobile device

4. Conclusion

With the development of smartphone performance, a mobile-based method provide a new way to acquire information on jobsite. To real time visualization the status of building environment，an approach of reconstructing indoor scenes on a hand-hold mobile device is presented in this paper. Capturing 'as-built' spatial data by a smartphone is inexpensive, portable, easy to operate and convenient to inspect for foremen. Oriented FAST and Rotated BRIEF (ORB) feature-based Simultaneous Localization and Mapping (SLAM) is proposed to estimate the camera trajectory and generate a sparse point clouds model on the smartphone. The sparse map transmits to a computer to implement subsequent process for generation a grid 3D model, and then transmits back to the smartphone for inspection.

Future research, however, should focus on real jobsite applications (e.g., large-scale, far-range, poorly textured, etc.) Notably, the comparison will be demonstrated in both laboratory and actual field experiments. The model presented in this paper was reconstructed by using a monocular camera. In order to obtain precise geometry measure of the model, binocular camera will be introduced to complete the reconstruction in future work.

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Quantitative ways of measuring client's preferences: a step toward creating an intelligent architectural design agent

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Abstract

Technology-driven and digital modeling developments are undeniably changing design and construction professions across the architecture, engineering and construction (AEC) industry. Today, it is impossible to conceive of an architectural practice without using computer tools right from initial design conceptualization to the creation of construction drawings for a given project. The computer applications delivered new capabilities to automate the design process and offered various possibilities of assistant to the designer. However, they are not smart enough yet to understand clients or end users' (e.g. building occupants) needs or expectations and innovate a building design. Artificial Intelligence (AI) could be a solution to making architectural and building design process less time-demanding and more organized with minimal manual interference. The ultimate aim of this study is to make AI part of AEC's digital journey, by making an intelligent agent able to both understand client needs and produce building designs. An intelligent design agent is defined as an autonomous entity that perceives client needs and makes design decisions towards achieving client satisfaction while balancing design and technical objectives. There are two challenges with respect to creating intelligent design agents; (1) finding quantitative ways of measuring client's needs and preferences, and (2) providing a mathematical framework for making design decisions. This study focuses primarily on the first challenge and proposes a solution for creating measurable data about the client's needs and preferences. First, an overview of technologies that support quantitative measurement of people's physical, emotional, and behavioral characteristics is presented. These technologies include eye tracking, facial expressions, electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), and galvanic skin response (GSR). This overview will enable us to understand potential applications of psychological measurement in the AI domain. This will be followed by a hypothetical design experiment to test the hypothesis that we can determine a subject's degree of satisfaction by recording and analyzing his or her eye-movements and facial expressions when presented with a collection of visual data, like window design options on a screen. The participants are provided with window design options and asked to evaluate each design based on their preference by giving it a score. While study subjects complete evaluation tasks for each design option, we record their interactions using eye-tracking and an automated facial expression tool. The objective is to find a relationship between subjects' preferences (as the independent variables) and the emotion expressed and the time spent on each design (as the dependent variables). This will allow us to provide a first look at how subjects interact with different attributes.

Keywords: Eye-tracking; Facial expressions; End-user sstisfaction, Building design

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1. Introduction

The first stage of the design process is evaluating the clients' needs and requirements but the final design does not necessarily meet users' satisfaction and expectations. Although the integration of computers and various revolutionary programs massively aid in the building design process and help avoid multiple issues that may arise, the design process is not entirely computerized yet. The integration of building end users in early design stages has been addressed and highlighted by various researchers [1]; however, the automation of that process has not yet been studied in detail. Building occupants are people who spend most of their times indoor and do not necessarily have the knowledge for designing the building; yet, they may have preferences about the way it has been designed and built [2]. The computer applications delivered new capabilities to automate the design process and offered various possibilities of assistant to the designer. However, they are not smart enough yet to understand clients or end users' (e.g. building occupants) needs or expectations and innovate a building design. Self-learning systems, known as artificial intelligence (AI) are changing the way architecture is practiced, as they do our daily lives, whether or not we realize it. In recent years, AI has been used in lots of projects since it is now able to show emotion but its application in design is still less explored but gradually gaining impetus. One of challenges is a design should be visually eye-catching to consider it as a good design. To overcome this challenge and integrate user's perception in the design process, the use of eye tracking technology as well as facial expression has been suggested. Eye tracking investigates user's perception of real-time reaction to design, while conventional methods (i.e., interviews, focus group, questionnaires, etc.) have generally failed since they depend on users' willingness and competency to express their feeling about that particular design. Recent studies found that user's needs is not solely about functionality, and they have transformed to more empirical perspectives, not only encompass usability, but also socio-cognitive and emotional aspects of user experience such as joy, surprise, sadness, positive feelings interacting with design, etc. [3].

To this end, the ultimate aim of this study is to make AI part of architecture, engineering and construction (AEC)'s digital journey, by making an intelligent agent able to both understand client needs and produce building designs. AI has the potential to influence the architectural design process at a series of different construction stages, from site plan to building operation and could be a solution to making architectural and building design process less time-demanding and more organized with minimal manual interference. In the context of architectural design, AI can be designed as the use of computers to simulate architect's intelligence and perform activities normally considered to require architectural knowledge. Although there are various different definitions of AIs, a common view of an intelligent agent is a system that perceives its environment and takes actions that maximize its chances of success [4]. The architectural design environment is faced with a variety of design considerations and client's expectations. A schematic of the intelligent agent model is provided in Fig.1. The perception of an intelligent architectural design agent is the capability to interpret client's expectations in a manner that is similar to the way humans use their senses to relate to the world around them. Currently, there is no accurate and through definition of great design. However, if we can measure and quantify users' emotional and biological data as they interact with buildings, it can be included in the design. The use of eye tracking technology to measure users' satisfaction seems to be a suitable approach to achieve this objective. In particular, this study compares eye fixations as well as facial expressions to the scores provided by the participants in order to understand whether user's satisfaction can be accurately predicted by the use of this technology.

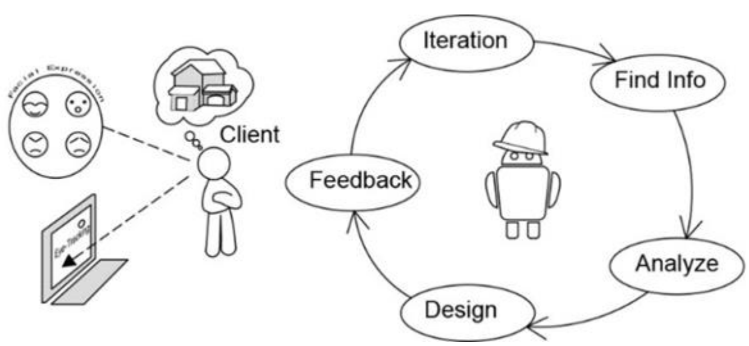

Fig. 1. Schematic of the intelligent architectural design agent

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2. Background

Many studies have explored the automation of building design; however, the complete digitalization of the building design process has not yet been achieved. Although technology driven developments are shaping the fundamental cores of the AEC industry, there still lays a gap in achieving total client satisfaction. Several of the technologies used in the Human-Computer Interaction (HCI) domain can facilitate the ability of machines to process client's needs and understand them. These technologies include eye tracking, facial expressions, electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), and galvanic skin response (GSR). The use of eye tracking technology was previously explored in relevance to different applications, some of which examined the HCI as well as user's satisfaction with web design. Sharma et al. (2014) highlighted the issues, scope, and limitations of the implementation of this technology to test a specific interface. They discussed the level of usability of eye tracking technology as a method HCI and summarized the different measurements of eye tracking techniques, such as fixations, saccades, pupil size, and blink rate. They found that eye tracking systems were proved to be resourceful in usability testing and an indication of satisfaction which make it possible for HCI aiding in decision making process [5].

Khalighy and Green (2015) developed a methodology for quantifying visual aesthetics in a product design by the use of eye-tracking technology. The obtained results were compared to declared preferences by the contributors. It was found that number, duration, and coordinated of eye fixations can certainly indicate accurate approximations to the product preference and satisfaction, solely based on aesthetics. This proves the plausibility to objectively evaluate designs before being taken into construction and manufacturing processes [6]. Ding et al. (2016) conducted a study to test the feasibility of using eye tracking technology to measure and assess the product design. Two different tasks were designed for this study in order to analyze the captured attention and its relation to the user's experience. Two factors were focused on throughout the tasks; first fixation and pupil dilations. It was concluded that time to first fixation, fixation time, and minimized pupil variations can be used to indicate end user preference and satisfaction [7]. The probable correlation between eye movements and end-user perception associated with modern web-based EUD (End-user development) environments were studied by Tzafilkou and Protogeros. The aim of this study was to assess whether end user perception and acceptance can be measured by eye behavior. Overall, the study confirmed the significant bond between fixation on eye position and end-user perception [8].

Furthermore, many studies highlighted the missing gaps of using eye tracking technologies to determine end-user satisfaction. The state of the art problems that were raised from previous researches of eye tracking technology are mentioned by Fengpei (2006). Some of the patterns that appeared in the usability studies were stated including a number of fixation points, time at fixation points, and average fixation time. Some of the concerning matters when dealing with eye tracking technologies that were highlighted are: eye movement data being lost, accurate extraction of eye data, and appropriate interpretation and explanation of the data collected. In the conclusion of this paper, it is advised to conduct future research answering to the previously mentioned issues of eye tracking technology [9].

In support of building end user incorporation in early design phases, the matter of whether an advanced level of user contribution can be used as an approach to develop sustainable energy technologies and buildings was raised by Ornetzeder and Rohracher (2006). Their study focused on user-led innovations managed by high levels of participation from different end-users. The results showed that the involvement of users in the design was extremely helpful and result in better-quality and more sustainable buildings [10]. Moreover, Ochoa and Capeluto (2008) conducted a study to examine the impact of integrating building intelligence to improve building energy performance and user comfort. They mainly highlighting the importance of the decisions made at early design stages rather than those added at the end. The result proved that truly intelligent buildings are a product of a design progression that integrates intelligence as well as end-user needs [11]. Though there are many efforts to participate building end-users in the design process, an efficient method of doing so has not yet been defined. A complete automation and computerization of this process at the conceptual phase of design would assist the achievement of ground-breaking means of efficient, sustainable, and intelligent building designs. A couple of studies discussed the use of eye-tracking and facial expression analysis as a method of evaluating the building end-user perception. Mohammadpour et al. (2015) concluded that higher visual attention was indeed assigned to parts that were more attractive to the [12].

Moreover, Amiri et al. (2015) highlighted the fact that the combination of facial expression analysis along with eye-tracking data enhances the accuracy and evaluation of user satisfaction [13].

To conclude from previous studies, the use of eye tracking technologies seems like a suitable way to introduce AI into the current building design process. When mastered, this could aid reach better user-oriented sustainable designs with less effort and time wasted in communicating clients' needs, requirements, and rework. The addition of facial expression recognition analysis along with the data collected by eye tracking provides the possibility of addressing some of the reliability gaps in the use of the eye tracking technology on its own. The ultimate goal of this study is to create an intelligent automated design process.

3. Methodology

The use of eye tracking technologies along with facial expression analysis provides the means to quantify the building's end-user satisfaction level. The eye-tracking experiment was conducted in a quiet and soft light lab using Tobii X2-30 compact eye-tracker to record eye movement data. The technical specification of the eye-tracker includes gaze accuracy of 0.4 to 0.5-degree range, precision of 0.32 to 0.45 degrees, data rate 30 Hz, freedom of head movement 50 (width) 36 (height) × 90 (depth) cm, calibration 9 points (~15 seconds to complete), monocular and binocular tracking capability. To set up this experiment, the eye tracking software (iMotions 6.1: human behavior research, simplified software) was set on screen recording mode and was linked to the slideshow. A simplified experiment was designed consisting of various options of window designs with minor adjustments in a form of the slideshow as shown in Fig.2. The first slide consisted of directions that explained the process requirements. Each slide compared between two different window designs; both their front view and angled view were shown (refer to Fig. 2). The participant was asked to look at the designs for a set period of time (10 seconds), write down a score from 1-6 (1 being the worst, 6 being the best) for each design (e.g. both preferred and undesirable design options), and then click on the preferred design. According to the participant's preferred design option, a different set of designs was shown on the next slide. The participant was to repeat the process until the slideshow ends.

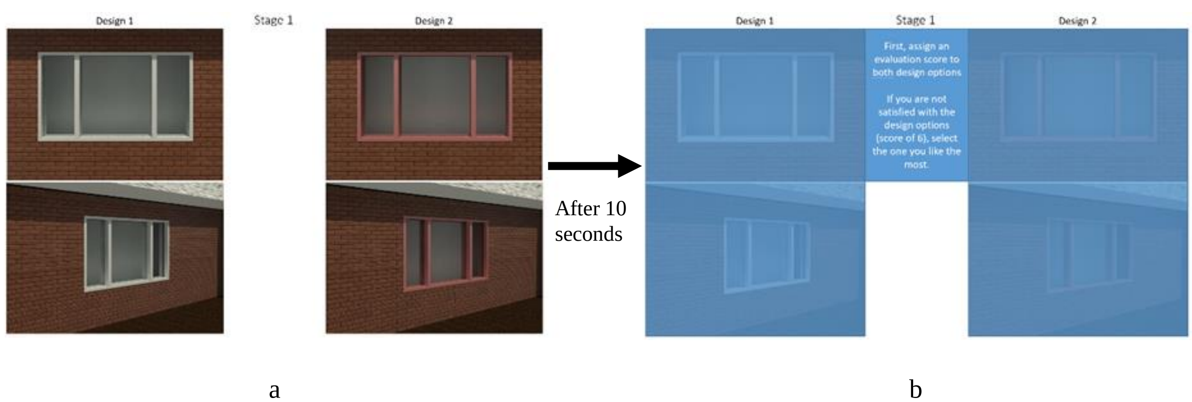

Fig. 2. (a) experiment slideshow; (b) instructions shown after a set period of time

This is a within-subjects experiment in which every single participant was subjected to every single window design. The facial expression recognition software (i.e., iMotions – Emotient) analyses the pattern of wrinkles and crevices based on a visual database of facial expressions and shows seven basic emotion indices including anger, contempt, disgust, fear, joy, sadness, and surprise and two aggregated emotion indices; positive and negative. Positive emotions are defined as emotions that are positively correlated with the evaluation scores and negative emotions are the ones with negative correlation. The Emotient engine (formerly known as FACET and previously CERT) automates Paul Ekman's FACS coding system (Ekman and Rosenberg 1997) and uses a neural network to analyse the pattern of wrinkles and crevices created by different facial expressions. Main outputs are: 7 basic emotions, 2 advanced emotions including confusion and frustration, 33 facial landmarks such as corners of the eyes, the tip of the nose, and mouth, and operational distance of 70 cm. The emotion index scores ranged from 0 to 5, higher numbers on the emotion index indicate higher levels of feeling (e.g., happiness).

To perform this experiment, first a pilot study was conducted to ensure accuracy. To start, the participant had to provide their name, age, and gender. Next, the eye tracker device was connected to the software and made sure to be working. Then, the calibration process was done to ensure the participant's eye movements were accurately recorded. When the calibration process was successful, the slideshow started. Throughout the experiment, the tracker device collected data, and so did the camera for the facial expressions data. Twenty people of different ages and genders participated in this experiment as shown in Fig.2. Out of 20 participants, half of them were male and the other half was female. The average age of the participants was 24 with the standard deviation of 3.9. All participants had normal or corrected-to-normal vision.

Since the data was recorded as a video, areas of interest (AOI) were defined before the experiment in order to analyse eye-movements. AOI(s) are relevant areas of the stimulus and are closely connected to the research question and the corresponding research design. For each AOI, several measures were calculated using iMotions: time to first fixation (time from the start of the design displayed until the participant fixated on the AOI for the first time), total fixation duration (duration of all fixations within an AOI), fixation count (number of times that a participant fixated on an AOI) and revisit (number of times that a participant returned to an AOI), and pupil diameter and dwell time (the sum time of fixation and saccade) for both views (i.e., front and side). More details on the eye movement measurements and experiment setup can be found in Yousefi et al. (2015). The measured eye-movement data was then compared to the scores given by the participants whilst conducting the experiment. The facial expression data was also recorded and compared to develop a trend. The correlations between subjective evaluation and eye-movement as well as the t-test analysis were conducted by SPSS 22.0 [14].

The setup of the slides presented to one of the participants based on the preferred designs along with the heat map is shown in Fig.3. Heat map shows the areas with a large amount of interest and the aggregated eye fixation of those areas which is shown in red. The absolute duration heat maps are created by combining data from all of the participants to provide a quick view of average existing viewing patterns. Heat maps clearly show which objects capture participants' attention in an area. Although the absolute duration heat map demonstrates the average viewing pattern, the heat maps created per each participant for each image present individual visual attention.

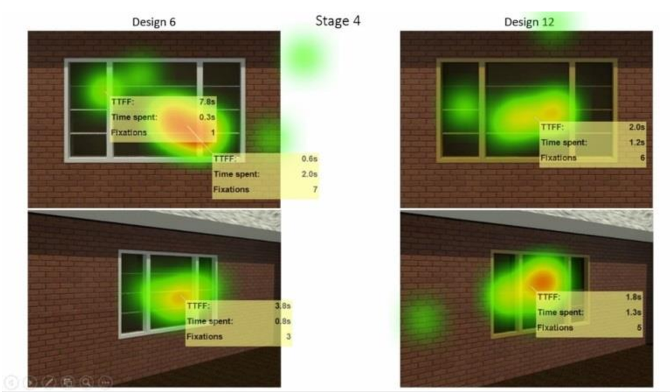

Fig.3 (a). Heat Map


Fig.3 (b). A participant taking the experiment

4. Results and discussions

Data on the target variable (i.e., evaluation score) is presented in Table 1. In the experiment, each participant was asked to complete 4 evaluation stages within about 1 minute. The participant was asked to evaluate two design options per stage and label a 6-point evaluation score to each design option, where 6 means the most satisfactory (or excellent) and 1 means the least (or poor). Then they would be guided to continue with the preferred design option (e.g., higher evaluation score) to the next evaluation stage. From Table 1, it can be observed that the average score for design options for all participants was 4.0 while preferred design options received 49% higher scores compared to undesirable design options. Another observation is that evaluation scores for preferred design options gradually increased when moving from one stage to another.

Table 1. Average values of evaluation scores in the window design experiments

	Undesirable Design	Preferred Design	Total
Stage 1	3.1	4.7	3.9
Stage 2	3.1	4.7	3.9
Stage 3	3.8	4.9	4.3
Stage 4	2.9	4.9	3.9
Overall Evaluation	3.2	4.8	4.0

The results of two-sample t-test associated with a 95% significant level for the window design experiment is shown in Table 2. The null hypothesis states "there is no difference in means response between eye movement measurements (i.e. fixation and time spent) or emotion indices (i.e., fixation, time spent, joy, positivity, sadness, and surprise) and preferred and undesirable design". The significance (2-tailed) value for fixation time periods is 0.005 which means that there is a statistically significant difference between the mean number of fixation time for preferred and undesirable designs. Fixations are those times when participants' eyes essentially stopped scanning about the design option. Since the fixation time average for the preferred design is greater than undesirable design, we can conclude that participants stare more at preferred design options compared to undesirable options. Although the difference in spent time between preferred and undesirable design options was not statistically significant ($p>0.05$), but participants spent more time on designs with higher evaluation scores. In addition, all the studied emotion indices including joy, sadness, positivity, and surprise are statistically significant at the 95% confidence interval (Table 2). Similar to a picture which is worth a thousand words, our faces can reveal lots of information. Facial expressions may have advanced as efficient methods to transmit feelings and intentions and make it possible to communicate intelligent emotions with a simple raised eyebrow or curl of the lip.

Table 2. Quantitative analysis of t-test for different window design experiments

Variables	Design Evaluation	Mean Score	Std. deviation	F	Sig. (2-tailed)
Fixation	Preferred	7.18	4.03	0.672	0.005
	Undesirable	5.48	3.55		
Time Spent	Preferred	2.12	1.28	0.008	0.078
	Undesirable	1.72	1.57		
Joy	Preferred	1.04	0.38	0.64	<0.001
	Undesirable	0.49	0.31		
Positivity	Preferred	1.07	0.40	0.45	<0.001
	Undesirable	0.53	0.32		
Sadness	Preferred	0.48	0.19	31.8	<0.001
	Undesirable	0.77	0.40		
Surprise	Preferred	0.47	0.19	32.7	0
	Undesirable	0.76	0.38		

The Pearson correlation between the evolution scores and the eye tracking and emotion indices is shown in Table 3. The correlation between positivity index and participant's evaluation is higher in compare with other indices (correlation coefficient = 0.633) and statistically significant at 95% confidence level. This means that there is a very close relationship between positivity index and participant's evaluation scores. In another words, participants showed relatively higher positive emotions for the designs (or components) they liked. The correlation between joy and participant's evaluation scores is moderately high which indicate a close relationship between them. The negative significant correlation at 95% confidence level exists between both sadness and surprise with participant's evaluation scores (respectively, -0.432 and -0.467). This means that low evaluation scores were associated with high surprise and participants expressed higher sadness emotions for the designs (or components) they disliked. Both fixation and time spent have a positive correlation with participant's evaluation scores and are significant at the 95% confidence level.

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Table 3. Comparison of eye tracking and emotion indices with evolution scores

Variables	Pearson correlation	Significance
Fixation	0.372	<0.001
Time Spent	0.249	<0.001
Joy	0.578	<0.001
Positivity	0.633	<0.001
Sadness	-0.432	<0.001
Surprise	-0.467	<0.001

The correlation between eye movement measurements and emotion indices and evaluation score is illustrated in Fig. 4. Correlation plot is the visual presentation of a matrix of Pearson's rank correlation coefficients between each variable. The trend line showed in red indicates the direction between each variable and evaluation score and the black circles show the level of strength between them. A positive association exists between fixation, time spent, joy, and positive emotion with evaluation score while the sadness and surprise have a negative association. In addition, these figures illustrate a linear relationship which means that the points on the scatterplot closely resemble a straight line. A relationship is linear if one variable increases by approximately the same rate as the other variables changes by one unit.

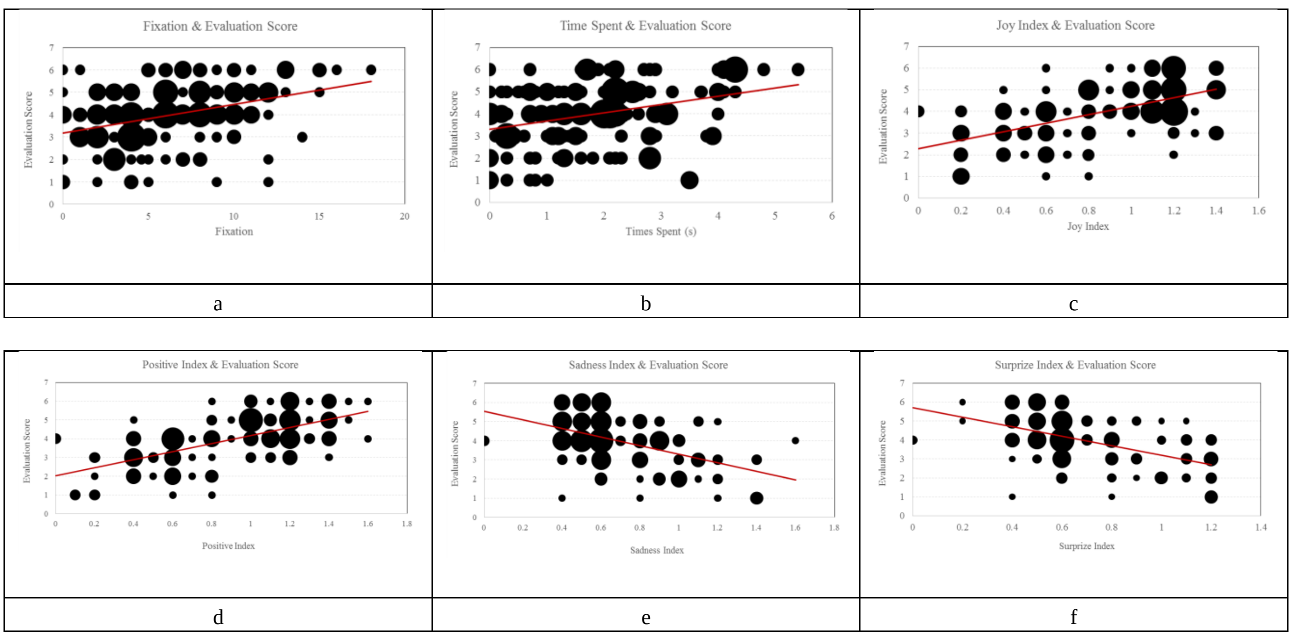

Figure 4. Correlation plot between eye movement measurements and emotion indices and evaluation score

5. Conclusion

The ultimate aim of this study is to make AI part of AEC's digital journey, by making an intelligent agent able to both understand client needs and produce building designs. As a first step toward achieving this goal, in this study a quantitative method was used to measure building end-user satisfaction at the early stages of design process. To achieve this objective, twenty people were asked to look at a set of two different window designs at each stage, evaluate both designs, and select a preferred one. Meanwhile, their eye movements were being tracked and recorded in addition to their facial expressions and reactions to the presented designs. A statistical analysis using SPSS software was performed to analyze the collected data. The results of two-sample t-test showed there is a statistically significant difference between the mean number of fixation time for preferred and undesirable designs at 95% confidence interval. This means that participants stare more at preferred design options compared to undesirable options. However, the difference in spent time between preferred and undesirable design options was not statistically significant (p>0.05), but it was found that participants spent more time on designs with higher evaluation scores. In addition, all the studied emotion indices including joy, sadness, positivity, and surprise are statistically significant at the 95% confidence interval. The correlation between eye movement measurements and emotion indices and evaluation score is illustrated in Fig. 4. Besides, a Pearson's correlation study was performed which showed a positive association between fixation, time spent, joy, and positive emotion with evaluation score while the sadness and surprise have a negative association. The combination of the data collected by eye tracking and that from facial expression analysis provides us with a better understanding of how people evaluate designs and rate their level of satisfaction. It provides us with the first step in creating a smarter and digitalized design process.

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Should BIM change the Language of Engineering Education?

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Abstract

Over the last decade the construction industry has been introducing building information models (BIM) as the way to represent buildings and communicate about them. In teaching engineering, we are also creating representations of buildings and communicating knowledge about them. While teaching, we conceptually refer to the very same real world objects that now have an explicit conceptualization in a BIM environment. This explicit conceptualization did not exist in the age of drawings and paper documents.

The question that this paper asks is this: Due to BIM, communication in the industry changed. Should communication of engineering knowledge – teaching – change as well and how?

While much has been written about teaching BIM and incorporating BIM into the curricula, this paper is exploring the general impact of BIM on engineering education. Based on a high-level model of engineering communication, five scenarios of the interplay between BIM-influenced engineering communication and teaching are presented. The paper argues that ignoring BIM may create a cognitive dissonance between study and industrial work. We are finding that the impact of BIM is twofold: vertically there is a need to establish a reference between knowledge concepts (in teaching) and information objects (in information models). Horizontally BIM is an integration technology that allows for a more holistic design and planning. Both the language of individual courses as well as cross references and synergies among courses should change. A “T” style structure of the courses around BIM is proposed.

Keywords: engineering education, building information modelling, engineering communication, curriculum development;

1. Introduction

BIM can stand for building information models, building information modelling or (most appropriate) building information management. It has radically changed the communication in the construction industry and the representation of buildings. Note: what we say about buildings holds true for any product of the architecture-engineering-construction (AEC) industry.

Radical is the change of communication language: the set of symbols and the way in which they can be combined to transfer ideas. In traditional communication, engineers used geometrical elements, formulae, numbers and natural language as symbols. How they can be combined was defined by standards about engineering drawings, rules of mathematical notation and grammars of natural languages. Intelligent human observer was able to interpret combinations of primitive symbols into complex engineering concepts. In a trivial example of Figure 1, she was able to recognize a beam with a concentrated load from a few lines on paper.

In BIM, the symbols are not generic geometric, mathematical or natural language elements but objects with properties. Objects belong to classes or families. The advantage of these objects is that computer algorithms, not just humans, can parse them and use the information associated with them. They are defined in a computer readable language. BIM standards strive to include all objects – all symbols – required to exchange information about

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buildings so that there is no need to resort to generic graphical or natural language elements. BIM defines a finite language to communicate about buildings that ideally would leave little to human interpretation. BIM equivalent of Fig. 1 is in Fig. 2.

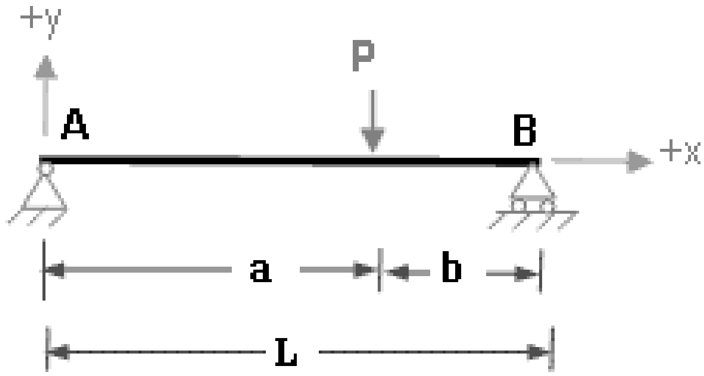

Figure 1: Beam with a load – unstructured representation.

```
/* beam A-1 - beam axis along global x axis ------------------------------- */
/* cardinal point = 1 - bottom left */
/* enhanced definitions intruduced in IFC2x4 - IfcBeamStandardCase --------- */
#1000= IFCBEAMSTANDARDCASE ('0juf4qyggSI8rxA20Qwnsj',$,'A-1','IPE220','Beam',#1001,#1010,'A-1',$);
#1001= IFCLOCALPLACEMENT (#100025,#1002);
/* set local placement so that the z-axis is co-linear to the beam axis ---- */
/* the y-axis (cross product of x & z axis) is up direction of profile ----- */
#1002= IFCAXIS2PLACEMENT3D (#1003,#1004,#1005);
#1003= IFCCARTESIANPOINT ((0.,0.,0.));
#1004= IFCDIRECTION ((1.,0.,0.)); /* local z-axis co-linear to beam axis */
#1005= IFCDIRECTION ((0.,1.,0.)); /* local x-axis */
#1010= IFCPRODUCTDEFINITIONSHAPE ($,$,(#1050,#1020));
#1020= IFCSHAPEREPRESENTATION (#100011,'Body','SweptSolid',(#1021));
```

Figure 2: Beam represented as an IFC object.

2. Related work

The research on the interplay between BIM and education took several directions: (a) how to teach BIM itself – mostly in the context of information technology courses and specialization [1,2,3, 4], (b) how BIM is changing the creative design process [5,6,7]. (c) how BIM is impacting construction management [8,9,10,11] and (d) how is BIM disrupting construction education in general [12,13]. This paper is in the last category (d). It draws from pedagogy research that is concerned with the construction of language and its impact on transfer of knowledge [14,15].

Research on the BIM pedagogy is slowly emerging. Eadie et al. [16] rightly claimed that BIM is more than just technological replacement for CAD and that it requires a new kind of pedagogy – generally a constructivist approach that claims knowledge is constructed by the learner rather than passed on from teacher to learner.

Hjelseth [17] explored three different pedagogical frameworks to integrate BIM with higher education: (a) Integrated Design and Delivery Solutions (IDDS), (b) Technological Pedagogical Content Knowledge (TPACK), and (c) Trinity of BIM as building information model/ -modelling/ -management (BIM3P). He suggested not to teach BIM separately but to make it an integral part of core architecture and engineering subjects. BIM disappears as a separate subject and becomes a tool for learning architecture and engineering.

3. Problem statement

To teach about architecture and engineering we use language. Books and lectures are in a natural language. Engineering concepts might have strict natural language definitions. When represented mathematically they get an implicit information model consisting of the values that mathematics manipulates. However, each discipline, each message (lecture) invents symbols on “as needed” basis. Not only are symbolic representations of a beam different in, say, Structural Mechanics Course and in Wooden Structures Course, there is no common set of symbols and no finite set of symbols.

But when these same students will start using BIM, such a shortlist of symbols (called objects or elements) with a shortlist of properties (called attributes) will emerge. In fact these terms are being standardized in an effort complementary to BIM standardization – in BuildingSmart Data Dictionary [18].

The question is, should the teaching of just about any topic of engineering take into account that there exists a list of symbols (terms) that are routinely used to communicate about buildings. Should those that teach vertical professional courses and are mentioning beams, columns, cantilevers, rebar etc. adapt their language and talk about ifc_beam, ifc_columns etc? Of course, without the ifc_prefix but in the data dictionally meaning. Should they take into account that in their mathematical models, they use values that are attributes of BIM objects? Should the textbooks of just about any engineering course be rewritten, so that language of (a) BIM based industrial processes and (b) natural or mathematical language of education would merge?

4. Communication Models in Industry and Education

This chapter presents semi-formal models of communication in engineering work and in engineering education. The models show that in engineering work the parties communicating are not just humans but software and robots, however, in the education process the communication is between teacher and student which are both human. The role human is a bridge between symbolic representations.

4.1. Knowledge communication

Knowledge has been defined as the ability to respond properly to a problem [19]. The response is a result of processes in the mind. In some cases, the response is information (i.e. spoken, written word); in others, a material activity (i.e. doing something). A well-established model that relates the real world to our understanding of it and to the words and symbols we use to communicate about it, is the meaning triangle [20] (Fig. 3). Things or objects (we shall call these “O”) are items from the real world. Experiences in the psyche or concepts (“C”) are ideas we hold about things in our minds. Words, drawings and other symbols (“S”) are used to so that we can communicate about our thoughts denoting real world objects.

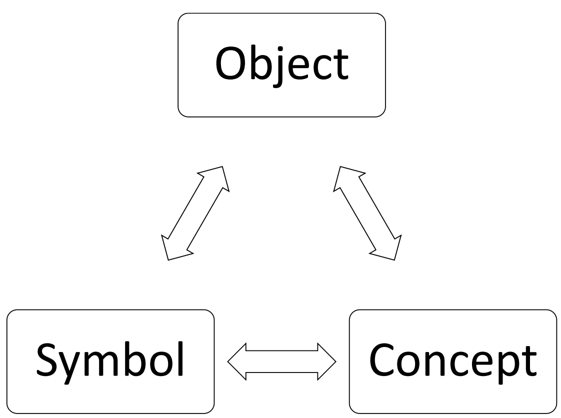

Figure 3: The semiotic (meaning) triangle.

In this context, learning is equipping the student with useful Concepts so that she can deal with real world Objects appropriately. Learning can happen in two ways.

First, on the C-O side of the triangle by gaining experiences in the real world. Experiential learning of – for example children - is happening in this way. It may also happen without creating a concept. We call this intuition. The point of schools is not to teach intuitions but concepts that can be represented with symbols and linked with among them with theories.

A second kind of learning takes place when we listen, view or read about real world Objects. Symbols, words, drawings, mathematical equations etc. are used for that. This learning is happening on the C-S side of the triangle. Most of the higher education learning programs are taking place along the C-S line. Students do not deal with real world objects but with their symbolic representations – like the ones shown in Figure 1. In vocational education there is practical work where learning takes place along the C-O side of the triangle.

Building Information Models are a very advanced form of a symbolic representation of buildings but are not the only way to represent buildings. Symbolic representations (models) are created to study real world phenomena scientifically or to teach about them. Several such models are created, specifically, for problem that is studied or taught.

4.2. Islands of education and conceptualization

One could argue that a phenomenon of "islands of conceptualization" exists throughout the construction profession, much like the "islands of automation" [21]. The latter idea was used to explain the problems of information exchange in the construction industry. The idea was that there exists computer software supporting specific tasks in the construction industry, however, each of these software programs is an island and can hardly talk to other software. Similarly, islands of conceptualization would mean that for different problems to be addressed scientifically and for different engineering subjects we teach, we choose to conceptualize the real would differently – we have many instances of Symbols and Concepts about the same real world Object (Figure 4). Another way of saying this is that there exist silos of knowledge and silos of learning – each topic in its own course, with its own textbooks and representations.

In teaching and in science this is not much of a problem. The conceptualizations are for human use. Teacher and student are humans. A student can switch from one conceptualization to another as she moves from class to class. Scientists in their silos each study the world with their own conceptualization.

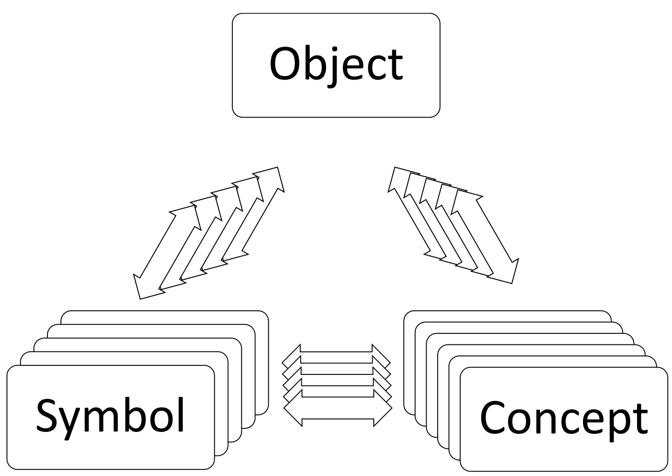

Figure 4: Multitude of Symbols and Concepts while teaching and learning about the same object.

4.3. Communication in Construction Industry

In practice, things are different. The solution for the "islands of automation" problem is supposed to be BIM – building information model - a common symbolic representation of the real would building that any software can use to get information from and add information to. There is a single real-world object that everyone is contributing to – the building being built. And there is a single social network of all people involved. These three elements – real world building, its digital representation and the social network are the three elements that are "integrating" construction industry and countering the fragmentational forces that are a result of a specialization of professions (Figure 5).

In this context construction is about changing the real-world Objects as specified in the Symbolic representations of building designs. Construction is happening on the S-O side of the triangle which has hardly been touched during the education process. Symbols (drawings, plans) are indeed interpreted by humans, but also by software and increasingly robots and other automation devices.

The communication in the industry used to be transactional – various people were communicating with each other, often inventing the symbolic representation fitting just the purpose of that communication act and that particular problem's conceptualization. What was going on in the industry was similar to what was happing in the classroom. In a BIM process, however, the information is not exchanged but shared and there exists a single symbolic representation for all purposes.

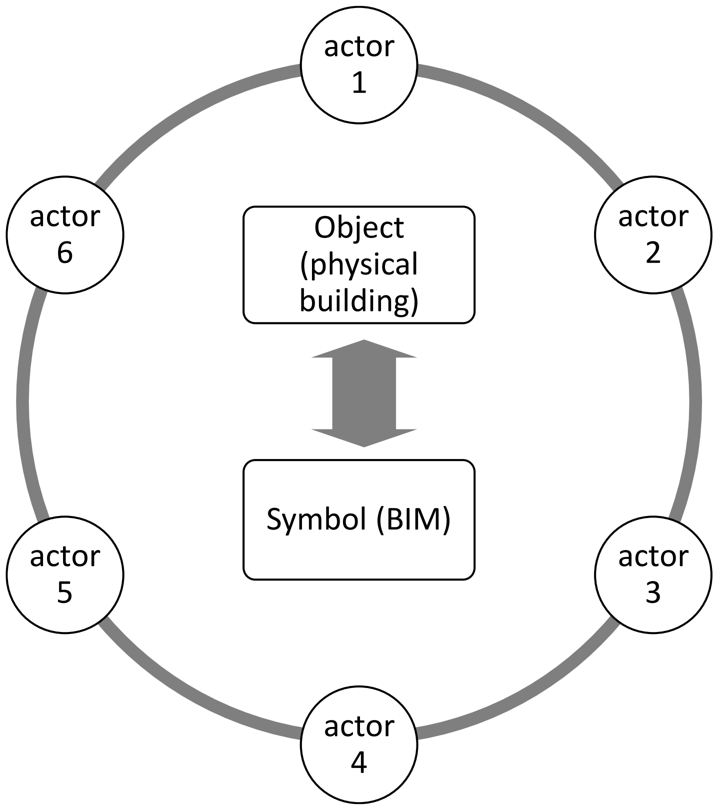

Figure 5: Single building, single symbolic representation, single social network of collaborators are integrating construction in practice.

5. Scenarios

The key problem identified in the sections about therefore is the growing difference in how the industry manages knowledge and information and how does the academia. The industry is forced – by the obvious fact that there will be a single physical building in the end – to integrate information and knowledge. With BIM and related tools it got a powerful tool to do so. Not so the academia. Few problems are caused if learning remains in silos. Until the students enter the workforce.

Therefore, the curriculum needs to change because of BIM technology. In this section we present five scenarios, five different levels on how this could be done.

5.1. Level 1: BIM modernizes teaching of CAD

In this scenario, the design communication courses that used to teach descriptive geometry and technical drawing and that used to evolve into courses on CAD, teach BIM as well. Instead of teaching the students how to document the designs using drawings, 2D or 3D geometrical models, students are taught the use of BIM modelling tools such as Revit, ArchiCAD or AllPlan. Skilled BIM modelers and BIM operators are a result.

Additional elective courses can be offered, for example Building Information Management for future BIM managers or BIM coordinators. Elective programming courses can be offered for languages such as C#, Pyton etc. to educate future developers of smart BIM objects and BIM software extensions.

There are hardly and changes in the structure of the curriculum. BIM is localized in a couple of courses.

5.2. *Level 2: BIM modernizes construction management*

In this scenario, those courses that teach skills that by their nature have an integrative role in the construction processes, take note of BIM. Such courses are courses about construction management. Management integrates varous processes, people, knowledge and resources into a construction process delivering a construction product. Project planning is BIM based. Crude Gannt and Pert charting evolve towards proper 4D BIM. Quantity take offs assume the existence of BIM. Financial flow management introduces the fifth dimension – 5D BIM. Organization and management courses educate future BIM coordinators and BIM managers. Creation of BIM Execution Plans, Information Delivery Manuals and similar documents becomes an integral part of construction management process and future engineers learn about that as a part of construction management courses.

Elective courses on strategic management of and with BIM may be offered as well.

Effects of BIM on education are still localized, however, a need for project based learning is starting to emerge so that management and design communication topics are taught integrally.

5.3. Level 3: Shallow BIM is used in vertical courses

In this scenario, starting in introductory courses on architectural and building design, BIM software is used as a toold for design evolution, and to communicate various stages of building documentation. Then students may switch to BIM tools to document designs created in vertical courses, for example Masonry Structures, Steel Structures, Reinforced Concrete, Bridges and Tunnels etc. In this scenario, these topics are still taught in isolation. Specialized software for the design of, for example, reinforcement, is still taught and used in isolation, however, to document design and communicate results, students switch to BIM software. They learn the language used in BIM software to discuss these concepts and can compare their attributes in BIM modeler software with the theoretical ones in vertical courses.

5.4. Level 4: Deep BIM is used in vertical courses

In this scenario, vertical engineering courses recognize not only the usefulness of BIM to document and share solutions but start using shared conceptualizations introduced by the BIM tools and standards. Vertical engineering courses take note of the concepts, their properties and their relations, as defined in BIM tools and vocabularies. There is an increasingly simple mapping between an attribute in BIM data structures and a variable in equations being taught. It is assumed all inputs can be retrieved from BIM database and all outputs can be stored into BIM database. Analysis software that is used, shares conceptualizations and exchanges information with BIM databases.

5.5. Level 5: Knowledge is BIMified

In this scenario, not only is BIM used to represent designs and to provide information source and sink for the analysis software. Also, professional knowledge, best practices, rules and standards – the knowledge of engineering – is beginning to be encoded as extensions in BIM software or an extension to model checking software such as Solibri [22]. Gradually, vertical engineering knowledge taught to students is not represented in natural language, textbook format but in a machine readable and automatically computable way. Teaching a vertical topic, for example Reinforced Concrete, becomes teaching about the principles behind the modules that can model-check that part of the model or propose design alternatives for that particular detail.

Of course, teaching follows the technology as model checking progresses into more and more intelligible tasks.

6. Conclusions and discussion

The paper has provided a theoretical explanation, why the entire curriculum will need to be modernized because the industry is communicating using BIM: in the industry, islands of automation are growing together, walls of the

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silos of activities are being taken down. In the academia, silos of knowledge could still be tolerated, because the bridging of knowledge could be accomplished manually. BIM is enabling computer integrated construction. Integrated construction calls integrated education.

In the paper, we have presented five different levels of responses of academia to BIM. Teaching BIM in isolation as a better CAD, via including BIM in integrative topics such as management towards an increasing reliance on BIM in vertical, specialized engineering courses. First for documenting designs, then in designing in BIM terms and finally for encoding knowledge in a BIM compatible way.

The last three levels call for an increasing change in the structure of the courses. Traditionally, specialized vertical courses are isolated from each other, as is the information and knowledge that they manage. BIM creates a shared representation of a building. Several courses are in a position to address the issues of the same building, each from its own perspective. This calls for integrated teaching in a project based way – it calls for “T shaped” courses where the vertical element in the letter “T” deepens the specialized knowledge the course was supposed to give. However, the horizontal element of the “T” connects to the common information model of the building and to the project students are working on (Figure 6).

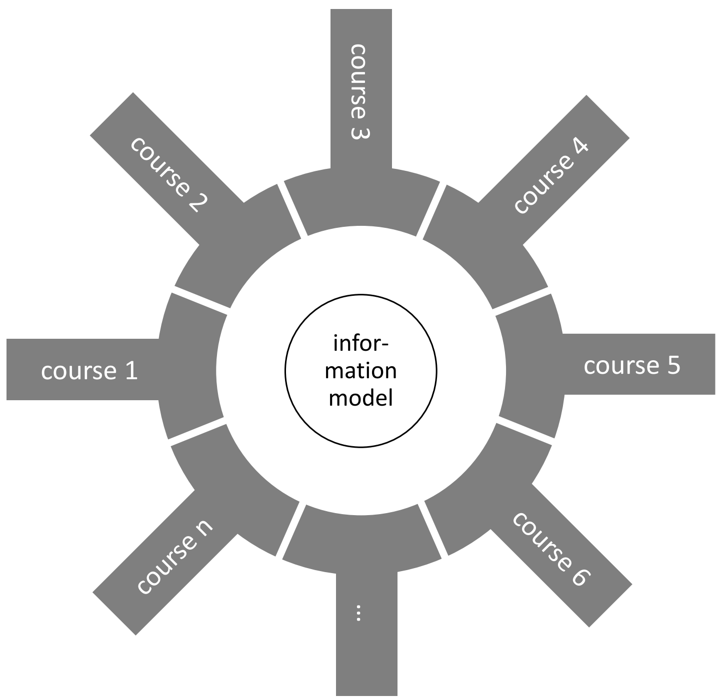

Figure 6: "T" shaped courses, integrating construction education around BIM.

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The Development of BIM-based Augmented Reality System for Fire Safety Equipment Inspection

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Abstract

The purpose of fire safety equipment inspection and maintenance is to enable the equipment to start correctly and perform its expected function when fire protection is required to achieve disaster reduction. In the current fire protection maintenance inspection operation stage, the content and methods of inspection stipulated by the regulations are to be followed. Therefore, the relevant file drawings must be consulted before the inspection and maintenance operations are performed. However, because the documents and files are still in paper form, it is difficult to determine and read the information on the inspection and maintenance operations. In addition, it is time-consuming as well as strenuous. To solve the above problems and to help inspectors obtain the information they need as efficiently as possible, this study uses the building information model (BIM) to build the components of fire safety equipment while simultaneously inputting data related to the components' life cycle into the Revit 3D model using the COBie Toolkit. The data are further organized into a cloud database to enable augmented reality processes such as visual simulation and the use of mobile devices in future inspections. This eliminates the limitations of paper-based documents. In terms of system development and case verification, this study used augmented reality technology to present visual simulation of the equipment. The selected case studies demonstrate that BIM ensures the integrity, accessibility, and efficacy of data, while the augmented reality technology combines data with physical objects to provide information immediately in a visible and convenient manner. The developed model therefore is an effective tool that efficiently meets the requirements of fire safety equipment maintenance inspections.

Keywords: augmenter reality (AR) ; building information model (BIM) ; construction-operations building information exchange (COBie) ; information exchange; fire safety equipment testing.

1. Introduction

In a project life cycle, the importance of a project in the operation and maintenance phase is not less than that in the planning and construction phase. Traditionally, there are still numerous paper documents recording the maintenance and management operations of a project. However, with the increasingly large and complex building scale, handover drawings and descriptions after the completion of a project cannot meet the needs of the owners for facility maintenance. The vast paper documents are not only to be preserved but must also effectively provide the required information for the maintainer [1], the absence of which leads to problems such as a tedious operation pattern, reduction in the maintenance efficiency, and increase in the maintenance cost [2].

It can be learned from relevant research studies that the causes of the difficulties in facility maintenance management operations originate from the incomplete and inconsistent information on buildings. For overcoming such a deficiency, prior research works proposed some advance practices. Tserng *et al.* designed a set of establishing processes for an electromechanical facility component database to organize the establishment and installation of electromechanical

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facility components (such as weight, position, and length) [3]. Zhang *et al.* suggested an optimization of a building facility maintenance management system in which the structures of the buildings were initially divided into different levels and then the maintenance equipment project was input. The time was set as finite and infinite in the linear programming, and the life cycle of the facility maintenance management optimization system was applied [4]. Although a facility maintenance management system can improve the work efficiency, the complexity of the system components in the system is still an important factor determining whether the data attributes can meet the information requirements of the operations.

In recent years, with the rapid development in the building information modeling (BIM) model, BIM has been used as the core of the project life cycle information integration. Its application and support in the design and construction phase have been effective. The attribute information of the components and visualized features [6] in a BIM model are able to present attribute data on the geometric appearance, space concept, as well as general objects such as building components of the facilities and windows. For example, Lin & Su utilized a two-dimensional (2D) barcode system to record various components and codes and combined BIM to promote the advantage of a three-dimensional (3D) system. This allowed the participants of the project to effectively develop a comprehensive understanding of the entire project information in the maintenance phase. Furthermore, the authors established a BIM-based facility maintenance management (BIMFMM) mode system based on BIM, wherein the maintainers used interviews and BIM to inspect the relevant facility maintenance records; thus, yielding a higher efficiency of the FMM [7]. However, in most cases, the application of BIM to the facility operation and maintenance phase was stopped after a preliminary study [8], and it has not yet been practical for actual FMM. In is because apart from the dependence of most of the current BIM model construction platforms on the design or construction requirements, the BIM data attribute framework still cannot include the information and content required by facility operation and maintenance. Additionally, to improve the application benefit of BIM, relevant research studies have indicated that the combination with argument reality (AR) technology would contribute to the information usage efficiency of a BIM model [9,10]. However, Chau *et al.* stated in their research [11] that the combined application of the AR technology and a BIM model still had a limited utilization benefit, where the important key was the necessity of establishing a feasible information collection mechanism to conform to the information requirements of the users.

To improve the aforementioned shortcomings, the method used in this study integrating the related facility maintenance pattern, information exchange standard, and relevant specification information by considering a BIM model as the core may be feasible and applicable for the FMM requirements. However, different types of information attributes, information usage, and information presentation mode still have to be considered so that the FMM application pattern based on the BIM model can be effectively implemented. Therefore, the research range is set as the facility maintenance phase of the life cycle. The analysis of the information needs of the facility maintenance application, describable multifaceted building standard element attribute structure, facility maintenance pattern, and BIMFMM application are discussed and studied in this research. We expect to achieve integrality, mobility, and validity of information usage as well as immediacy, visibility, and convenience based on the information provided by the integrated application of the BIM model and AR technology. Moreover, the research aims to further enlarge and expand the application of FMM under the developing framework of BIM.

2. Information analysis of facility maintenance management inspection maintenance

For a fire protection equipment, this study first establishes the delivery specifications conforming to the fire safety equipment inspection maintenance, then identifies the information delivery relation between the operations as a whole based on the information delivery framework proposed by NIST [12] and the overall process of the IDEF0 analysis information delivery, and next, forms the contents in accordance with the demands of the operation process.

2.1. Analysis of information content of fire safety equipment

The requirements of operation inspection maintenance of fire safety equipment can be classified as: (1) requirements ensuring the inspection maintenance operation when the receiving switchboard gives the light signal and (2) requirements for the routine inspection operation of the maintenance plan and fire protection regulations. In consideration of the actual operating phase, the fire protection equipment components can be categorized into: visible fire protection equipment (components visible to the naked eye) and non-visible building construction or fire protection equipment in decoration. Thus, the following two inspection maintenance information presentation patterns are proposed:

(1) Information presentation of visible fire protection equipment inspection maintenance

Visible fire protection equipment inspection implies that the fire protection equipment visible to the naked eye can be inspected by it by performing the regulatory inspection of the components and maintenance plan. Alternatively, when the fire protection switchboard raises an abnormal signal, the inspection personnel can enter the corresponding space where the signal originated to conduct the inspection operation with the naked eye.

Therefore, the preliminary concept for visible information is formed as shown in Fig. 1, which is regionally divided based on the fire alarm layout plan and integrated with the fire protection equipment inspection maintenance to acquire the inspection maintenance information content and build the cloud database in the information delivery phase. This allows presentation of the relevant maintenance information of abnormality of the fire protection equipment when the inspection personnel scans the mark tracking code in real time with mobile devices (e.g., smart phone and tablet computer) after noticing the abnormal light signal generated by the receiving switchboard. A routine maintenance plan and regulatory inspection can also present the inspection information content using this pattern.

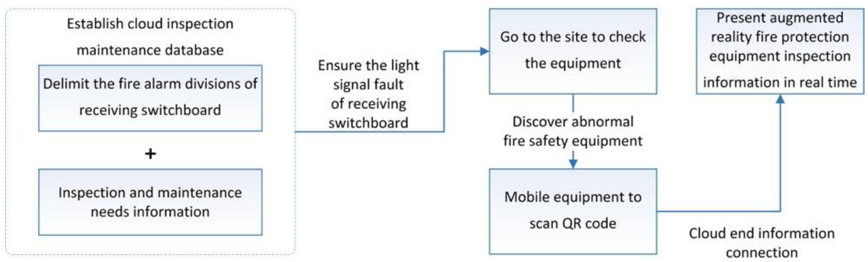


Fig. 1. Visible fire protection device inspection maintenance framework.

(2) Information presentation of non-visible fire protection equipment inspection maintenance

A non-visible fire protection equipment, which is built at the time of project planning and design, is planned for building structures or interior decoration. Thus, it increases the difficulty in the maintenance in the post-operational maintenance phase. However, the traditional maintenance operation mode in contrast with 2D architectural drawings, significantly increases the inconvenience of the maintenance. Therefore, this study will generate effective fire protection equipment delivery content via a BIM model and further establish a 3D cloud fire protection equipment component database by transforming the BIM file into a 3D model, which allows using mobile devices to scan the mark tracking code to obtain hidden fire protection information (as illustrated in Fig. 2).

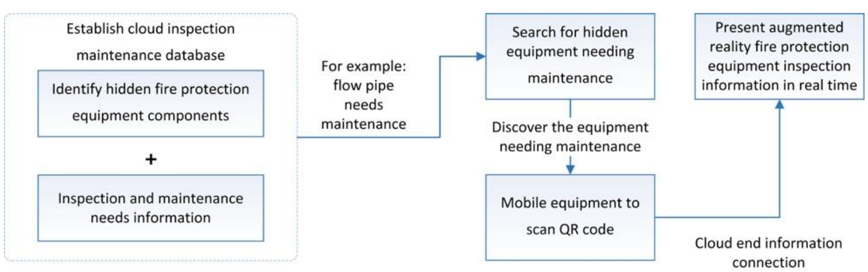


Fig. 2. Non-visible fire protection equipment inspection maintenance framework.

2.2. Establishment of inspection information application framework

A follow-up study will analyze the inspection operation process via IDEF0, as shown in Fig. 3, where B1 is the operation needed to be conducted when the fire safety equipment inspection is in process and its operation content includes site exploration and inspection according to a routine inspection or an abnormal signal from the receiving switchboard. After checking the equipment components of the project, the B2 diagnosis operation is followed to conduct diagnostic testing according to a regulatory testing. The equipment condition is examined sequentially based on the fire safety equipment examination table, and if no abnormal condition of the equipment is found, the fire protection equipment engineer selects the “equipment normal” entry on the examination table directly. However, if the equipment is abnormal, the fire protection equipment engineer proposes a fire safety equipment inspection report to conduct the B3 disposal operation, which is to send a maintenance unit to conduct the equipment maintenance according to the fire safety equipment inspection report and equipment operation handbook. If the abnormal condition can be solved immediately, the fire protection equipment engineer selects the "equipment normal" entry on the examination table, and in case the abnormal condition cannot be debugged instantly, the B4 operation is followed. In this operation, the fire protection equipment engineer proposes a fire safety equipment improvement plan to allow the management owner to implement it according to declared requirements and original completion document. Finally, the inspection operation is performed after the completion of the plan in B5, in which the manufacturer performs the repair according to the equipment design drawing, and the fire protection equipment engineer conducts the detection completion and inspection declaration after the completion of the repair.

Based on the above analysis results, this study will subdivide each operation into sub-operations on the basis of the fire safety equipment inspection analysis process, define the corresponding relationship between the sub-operations and participants, and classify the three types of information required by the COBie organization information framework to enable COBie Toolkit to provide more accurate information content. In this study, a COBie delivery handbook will be written after the development of the information requirements.

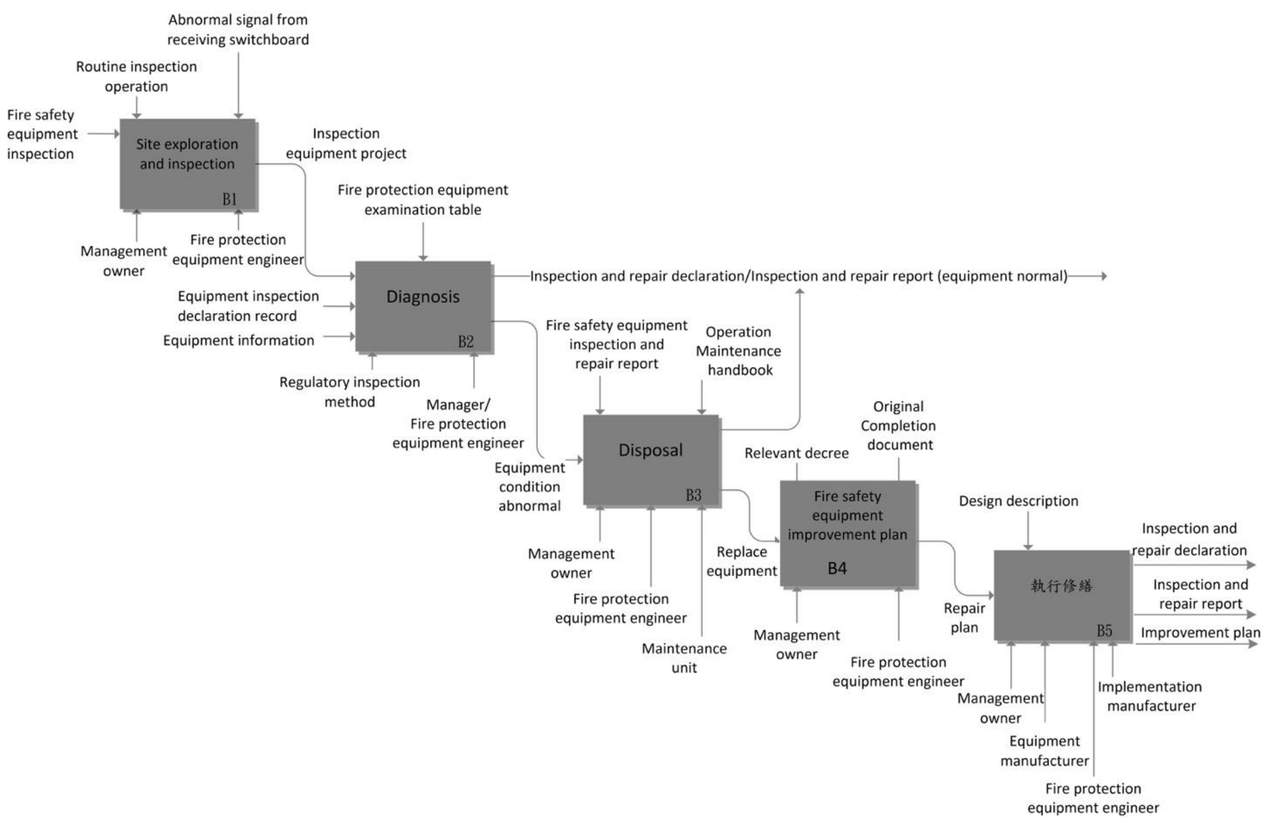


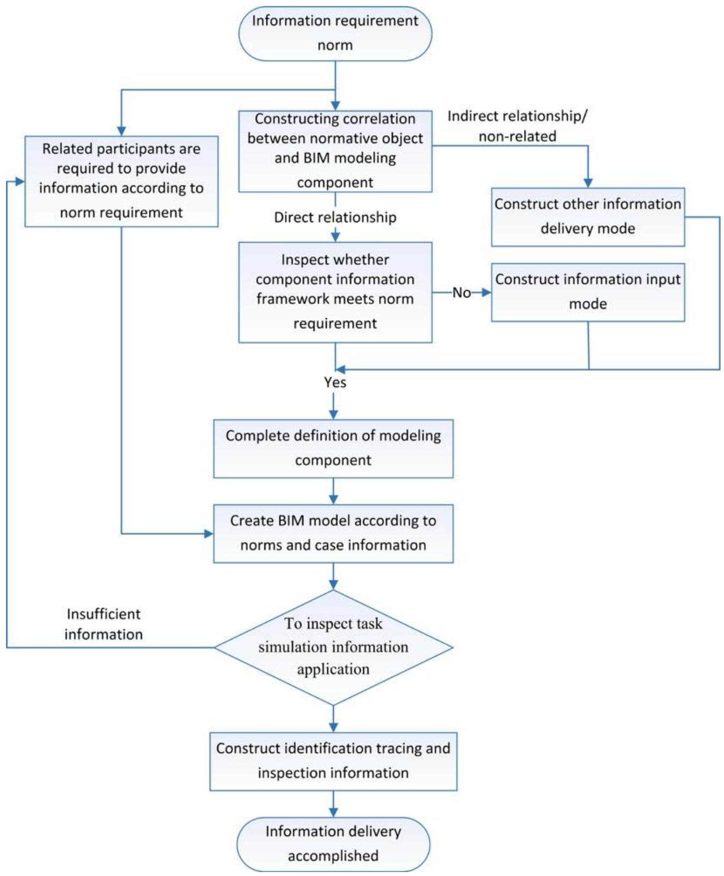
Fig. 3. Fire safety equipment inspection analysis process.

3. Construction of BIM identification tracing and verification mode

After the owner accomplishes information delivery standard, architects, contractors, and related units involved in the project develop a practical BIM model file according to the standards. After designing the file drawing, the owner must confirm whether each component is drawn according to the practical conditions and constructs the information content similar to the units involved in the construction based on the COBie organization requirement, to confirm the completeness and effectiveness of the whole project information delivery task.

This research uses Autodesk Revit 2016 as the modeling platform, constructs and links the COBie organizational information to the model via the COBie Toolkit application, concludes the content information required by fire protection safety equipment component inspection by the file format transformation and form arrangement of the BIM project information content. This is to present the inspection and maintenance information by identification tracing. Subsequently, this research paper clarifies the modeling content and provides the complete and effective visual information for AR. The following figure displays the BIM component construction identification tracing and inspection process, during which the simulation information application of the inspection task is verified. If the information present is unable to provide the related information for the participants according to standards, it is defined as insufficient information and the information content of the BIM model should be inspected again as shown in Fig. 4.

Fig. 4. BIM component construction and identification tracing and verification process.



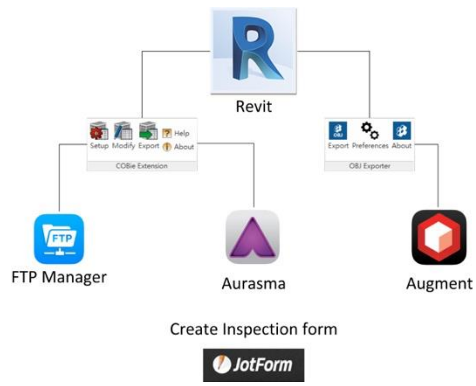
4. System construction and case validation

In this research study, the case validation system considers the administration building of a national university. During the process of the fire protection safety equipment inspection verification, first the regulations and inspection contents of the fire protection equipment should be known and then the information requirement of each component from the regulation inspection should be learned based on the defined component framework. Additionally, the information should be classified into the corresponding attribution of the liability and COBie organization structure via IDEF0 to generate the complete information delivery practice. Subsequently, the modeling staff is responsible for drawing the BIM case model according to the process and standards defined in this research. Then, the information required by the AR cloud end database is constructed and augmented by a format transformation, and the advantages and correctness of which is subsequently verified by practical cases. Consequently, the entire AR information delivery task is performed.

4.1. Construction of augmented reality cloud end inspection system

The construction of the AR cloud end inspection and maintenance system is completed based on the BIM model and COBie form. Prior to the system construction, the modeling staff should have a good knowledge of the cloud end database framework and be clear on the correlation of the construction of each database and the relevance of the construction. The framework of the cloud end inspection database designed in this research is shown in Fig. 5. The operating steps of this framework will be introduced subsequently. First, this system employs Revit 2016 as the BIM modeling platform and utilizes the Revit add-ins tool to export the COBie form and 3D model based on the model constructed by COBie Toolkit and OBJ Exporter to accomplish the AR framework. Furthermore, a mobile device application is used for the data construction. The data construction can be broadly divided into 3D model data and form (COBie form), file map, and file data. However, the 3D model data is the distribution of the inspection system pipeline for the inspection staff, and its corresponding application is called the Augment application, whereas the form (COBie form), file data, and file data application are the information of the inspection fire protection equipment for the inspection staff, and the corresponding application is FTPManager Free and Aurasma. Eventually, JotForm is adopted to construct a cloud end inspection feedback system, which feeds back the inspection result to the relevant maintenance staff and related unit in real time, stores the inspection result, and accomplishes the complete inspection and maintenance.

Fig. 5. The framework of the cloud end inspection database.



4.2. Verification of augmented reality and cloud database delivered information

In this research, following the accomplishment of the system, the relevant units (owners, maintainers, detectors, and fire device personnel) should confirm the information completeness and correctness by a case simulation. If any information error or omission is found, it is necessary for the relevant units in the project to correct it according to the specification requirements.

Because the COBie structure used is relatively complete, this research attempts to upload the COBie forms to the NAS cloud database and open Excel with the action device to directly extract the information required by each operation to realize immediacy, visibility, and convenience in information presentation.

In this study, the NAS folder applies the sheet name of the document in the Excel COBie forms for data establishment, and so herein, the folder is divide into system, type, and component. Thus, when the subsequent maintenance related units accept the detection results, it is feasible to open the Excel COBie forms using NAS to search for the corresponding files in in files of the document and examine the files and graphics.

In this research, system simulation is conducted based on the alarm signal from the receiver to test its real-time application. The function and effectiveness of the system information and operation introduction are discussed below.

(1) The fire alarm receiver sends the alarm signal: 1F-2 loop lamp at the north building is on.

(2) Allocate and detect the loop range:

A. Open the Augment application to scan the fire device detection entry (as shown in Fig. 6), and it is necessary to detect the loop range for reference.

B. Confirm the loop and components of the received images: confirm the fire source using the loop. If there is no fire source condition, open the application Aurasma, to scan the fire device detection entry corresponding to each component in the loop for the detection operation, as shown in Fig. 7.

(3) Failure detection diagnosis

A. Identify the fault component: fire alarm panel (manual alarm): log in FTPManager Free to refer to the regulation detection information.

B. Detect the results and causes: the manual alarm causes a button to short-circuit owing to dampness. Open the JotForm network detection forms to send the detection results to the maintenance-related units.

(4) Maintenance and repair operation

A. Maintenance-related units provide e-mail information: after confirming to have sent the name/unit of the detector, log in to FTPManager Free to examine the type of faulty component and open the Excel COBie forms to refer to the component type (Fig. 8).

B. Examine the product catalog: log in FTPManager Free: fire detection and maintenance system, type, fire alarm panel, catalog, fire alarm panel (wall-mounting type) (Fig. 9).

C. Change parts: when the maintenance unit checks the catalog, bring the relevant parts to the designated space only (when establishing the research component, it should be named after the space) for repair.

By the above simulation operation, it is feasible to examine and detect if the information content required by the maintenance operation is sufficient or complete. If there is any omission, the data builders can conduct data expansion based on the condition requirements to satisfy the convenience and completeness required by the detection and maintenance operation.

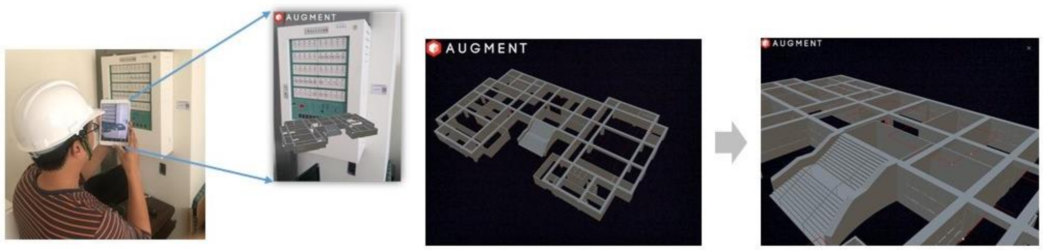


Fig. 6. Scan the fire device detection entry and detect the loop range for reference.

Fig. 7. Confirm the loop and components of the received images.

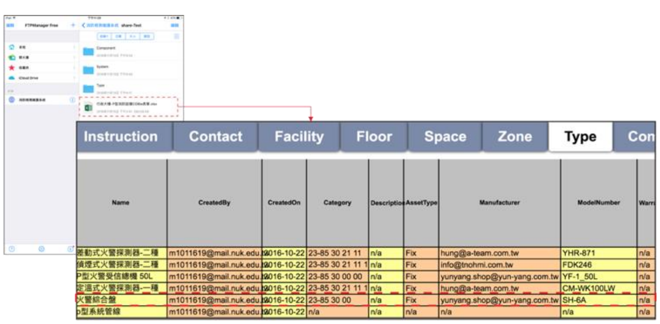


Fig. 8. Examine the type of faulty component in Excel COBie forms.

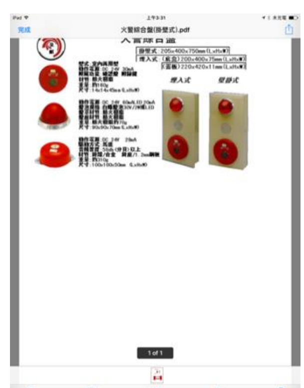


Fig. 9. Examine the product catalog.

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5. Conclusions

In this research, with the aim of detection and maintenance of the information by fire safety devices, the establishment of a BIM information model is attempted. Concurrently, based on COBie, expert interviews, information demands analyzed by IDEF0 and the information source in the project life cycle, the information should be organized by COBie to identify the complete delivery specifications that should be applied to establish the cloud database with the APP and NAS cloud memory servers of the organization. The online detection forms are established using JotForm to replace the traditional drawing records and realize real-time feedback to eventually form a detection and repair system consisting of fire safety devices that combine BIM and AR. Then, the feasibility tests of the system functions are conducted on actual cases and the testing results exhibit the effectively provided immediacy, visibility, and convenience of the data presentation of the fire detection and maintenance operation. The detection information system established in this research can assist detectors, fire device personnel, and maintenance units for effectively conducting the maintenance and detection operation in real time and solve the inconvenience caused by the requirement of drawing information. Thus, the system mode established in this research can satisfy the objective of this research. In addition, it can also be found from the analysis process of this research that though the research framework can analyze the information requirements and application modes, it remains difficult to analyze the specific information requirements owing to the lack of detection experience of the analyzers. Therefore, expert experience can exert a significant effect on the analysis process of this research.

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The Gradual Transition to BIM in Syrian Companies

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Abstract

The successful execution of construction projects, keeping them within estimated cost and the specific schedules primarily depends on the existence of an efficient construction sector capable of sustained growth and development in order to handle with the requirements of social and economic development and to utilize the latest technology in planning and execution. Many studies and researchers discussed the situation of construction in both of developed and developing countries; there is considerable dissatisfaction with the quality, cost and delay of construction, and Syria, not an exception.

The researcher suggested BIM as a tool to improve and innovate the building reality by using a good method to measure the performance of GCEC company in Syria; this method is the: BIM3 (BIM Maturity matrix) which is a tool to identify the current BIM maturity of organization or project team. It does not only give an indicator of the last performance, moreover, it helps the building's company in moving from measurement to management, and to anticipate needed changes in the organization's strategic, by measuring the current BIM level in the company through BIM maturity areas (TECHNOLOGY, PROCESS, POLICY) based on capability set v5 and key maturity areas at granularity level1 (initial, defined, managed, integrated, optimized) and putting recommendations for moving to next level. Successful accomplishment of these two tasks represents the foundation of good performance management.

Measurement provides the basis for an organization to assess how well it is progressing towards its predetermined objectives, help to identify areas of strengths and weaknesses and decides on future proposals. Performance measurement is not an end in itself, but a tool for more effective management.

Keywords: BIM; BIM maturity; building; performance; Syria

1. Introduction

Clients are interested in improving quality with reduced time, and cost, likewise contractors and architects are interested in performance improvements to increase their profits, meet client satisfaction and enhance their competitive advantages.

The complication and involvement of the different disciplines in construction processes form a complicated issue to manage; so the construction industry needs significant changes in its strategies.

Performance measurement is the first step and an essential agent of change, in another hand, performance management is a crucial concept that has taken on renovated importance in diversities of organizations. For a building company to make practical use of the results of performance measurement, it is a compulsion to be ready to move from measurement to management. It must also be able to expect required and accept the changes in its strategy; through improvements and raising the capacity of three fields: Technology, Process, and Policies.

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The researcher used "Building Information Modelling Maturity Matrix" BIM3 which is a knowledge tool for identifying the current BIM Maturity of organization or project team; and provided some recommendations in three BIM fields.

This step forms the first one to move to Building Information System (BIM) in Syrian building companies. General Company for Engineering Studies and Consultations (GCEC) has chosen as a case study to measure its reality and readiness to begin a gradual plan towards adopting BIM.

The reason of chosen is: GCEC is the largest and most important company in Syria in designing field. The GCEC is committed to quality, excellence and continuous development in its performance and a high level of creativity and taste, and the application of commercial quality standards through a team of integrated technical engineers and administrators with a good experience. The company's staff consists of 2190 employees working in locations spread throughout Syria. Staff always have proper training on the related programs; which leads to improve the situation of the company continuously and increase its productivity at the appropriate cost and promptly.

The agreement with the director of GCEC- Branch of Coastal Zone has done; aims to evaluate the performance of the company [1], and determinate of the extent of the company's ability and readiness with its engineering, technical, administrative, etc., to gradually move towards the application of BIM, and to make GCEC a first step towards pushing other institutions to go for competition.

1.1. The BIM Maturity Matrix (BIm3):

Performance measurement is a crucial agent of change, and performance management is a recognized conception that has taken on improved importance in changes of organizations [2]. Measurement provides the basis for an organization to assess how well it is progressing towards its predetermined objectives, help to identify areas of strengths and weaknesses and decides on future proposals. The evaluation method used in this research is "BIM3" which identified as a Knowledge Tool for identifying the current BIM Maturity of organization or Project Team. The BIM^3 has two axes - BIM Capability Sets and the BIM Maturity Index [3], [4]. To benefit from BIM3; it is essential first to review the concepts of BIM Capability and BIM Maturity:

BIM Capability refers to the minimum abilities of an organization or team to deliver measurable outcomes. As in figure 1.

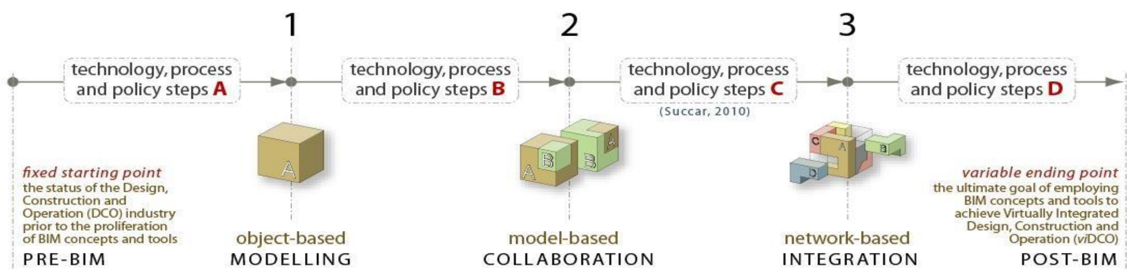

Fig.1 BIM Capability measured through BIM Stages separated by BIM Steps. Post 3 on the BIM Framework Blog

BIM Maturity refers to the gradual and continual improvement in quality, repeatability, and predictability within available BIM Capability. As in figure 2.

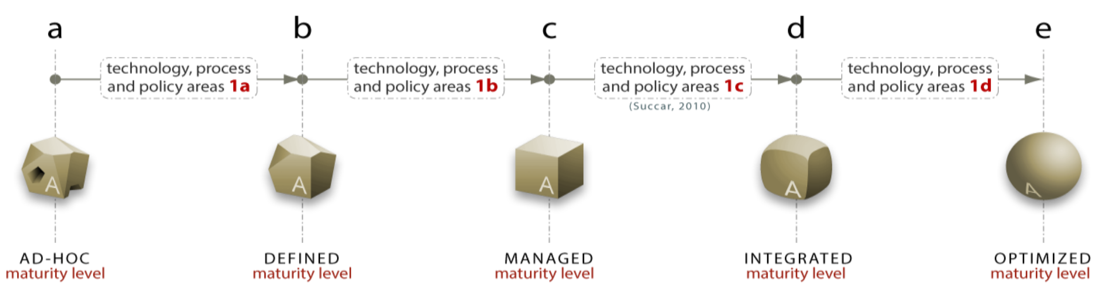

Fig. 2 BIM Maturity Index which has five levels. Post 10 on the BIM Framework Blog

The BIM³ is intended for low-detail organizational self-assessment (Organisational Discovery, Granularity Level 1). For best results, must follow the below-recommended steps:

- Identify the best person to lead the assessment effort – someone with significant experience in BIM tools, workflows and protocols and sufficient insight into the organization' systems.
- Manner this assessment as a group activity, a workshop with 3-9 individuals representing punishments and seniority levels.
- Set aside one hour to complete the self-assessment exercise and its follow-up discussions.

Assessment:

For each Capability Set (e.g., Software), read the full row within the Matrix before selecting the cell that best describes the organization's current BIM maturity level.

- Either use the recommended scores (10-40).
- Don't apply a score to a cell if the previous cell (to its left) has partial or no maturity.
- Don't calculate total scores (per column or per row) as these totals are deceptive.

Rating Results:

The matrix translated by the researcher and presented to a group of experienced engineers in the company (GCEC); a meeting held between them and the researcher to explain the matrix and its working structure. The engineers were asked to apply the precise method of processing and answering accurately for each cell after reading all the cells of each group, and to put a signal to clarify the cases achieved in the company after reading the entire line of each capability. The numbers placed under each cell are intended to determine exactly where the problem is and to discuss solutions, not to give an indicative number and computational ratio.

1.2. Main Maturity Areas: Technology

- Software: (applications, deliveries, and data): Company has achieved column b (specific) in addition to attaining one aspect of cell c; the final value is 11 out of 40. In this case, with cells with lower values, these cells have a priority in working to improve them. All cells must have this optimization. Therefore, to move the software in the company to the column (the subsequent cell) (orbit) entirely and also towards the integration and optimization as much as possible, for example:

• Setting strategic goals for the company and based on which programs are selected and managed
• Enable interoperability of various applications by proposing formats such as IFC, which helps to use, store, share and maintain data as part of the overall strategy of the company.

- Devices: (equipment, delivery, location/roaming): It took the assessment 0. Therefore the hardware is not suitable for the process of Building Information Modelling, so:

• Buying appropriate equipment for Building Information Modelling, and purchase workstation equipment that can be cheap or used but with good specifications (gradual change).
• Convince the management that the replacement and promotion of equipment is an investment.
• The standardization of hardware specifications within at least one team.

- Network (Solutions, Delivery, Security/Access Control): It takes a value of 0; which means that the network mode is not useful, you must look for the reasons.

• One solution is to secure the network and its solutions to ensure that information is shared between teams within a single organization and between organizations working together.
• Solutions can replace with innovations that are regularly tested and evaluated, such as: Ensuring proper bandwidths that allow storage and exchange of data and knowledge
• The allocation of project portals that allow for the exchange of significant data and make it interchangeable between the stakeholders in the project, leading to the participation of different parties and this reflected in

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improving the process and development of communication channels.

Table 1. *Performance Measurement Results, Main Maturity Areas: Technology. Author results, 2017.*

Performance Measurement Results			
Main Maturity Areas: Technology			
Capability set v5.0	Software: applications, deliverables, and data	devices: equipment, delivery and location/roaming	Network: solutions, deliverables, and security/ access control
Key maturity areas at granularity level 1 and Score	Defined (b) Score: 10	Initial (a) Score: 0	Initial (a) Score: 0
Recommendations	- Set the strategies goals for the company. - Enable interoperability of various programs by using IFC format.	- Buying appropriate equipment, and workstation. - Aware of the benefit of using BIM tools. - Standardize on hardware specifications.	- Secure the network solutions. - Manage solutions and integrate the Modelling process. - Allocate of project portals.

1.3. Main Maturity Areas - Process

- Resources (infrastructure, physical and precognition): Value of 5, the Company’s employees consider that the work environment and workplace tools directly affect employee motivation and productivity. So:

• Control this environment and secure the appropriate work tools and work on the management and integration, which achieves the company's performance strategies.
• Monitor the work environment regularly to suit the requirements of its employees and contribute to their ability to more work and productivity.
• There is also poverty in the way of exchange and sharing of knowledge. Also recommended using specific standards and shared data environment (like CDM) and commitment which will stimulate employees and increase productivity.

- Activities and Workflow (Knowledge, experiences and related dynamism): The value is 10 out of 40 as illustrated above. There is good knowledge of an essential section of the company's members about BIM and its benefits and the need to apply it. So that:

• A BIM team should be formed, roles of all participants should be defined, and the technology should be introduced into a small pilot project, and then they become essential in the company work.
• Create a spirit of cooperation and provide the necessary communication tools within the working group and within the organization in general.
• Gradually replace the traditional teams with newly trained teams. Or training the existing teams gradually so that the transition doesn't cause any defect or delay in the work of the company.

- Products and services: (specification, differentiation, research, and development): Based on the answers of the company engineers, it took value 10.

• The company recognizes that it uses a unique statement to define the specifications and characteristics of the components of the 3D model, but there is no individual standard (such as an integrated BIM model which serves as a reference model for mensuration) can be consulted indicating the specifications to be achieved if the model is submitted.
• To reach a product with high specifications; must specify the specifications for the progress of the model and control the product in the desired stages of development.
• Adopt a national or international code.

- Leadership and management: (organizational, strategic, managerial, communication, invention, and innovation): The rating is 0.

• The first important step is to persuade the management to move to the BIM and provide all the supporting factors.
• Cooperate with the supplier and develop a method to deal with him.

Table 2. Performance Measurement Results, Main Maturity Areas: Process. Author results, 2017.

Performance Measurement Results				
Main Maturity Areas: Process				
Capability set v5.0	Resources: infrastructure, physical and precognition	Activities and Workflow (Knowledge, experiences and related dynamism)	Products and services: (specification, differentiation, research, and development)	Leadership and management: (organizational, strategic, managerial, communication, invention, and innovation
Key maturity areas granularity level 1 & Score	Defined (b) Score: 5	Defined (b) Score: 10	Defined (b) Score: 10	Initial (a) Score: 0
Recommendations	- Work on the management and integration. - Monitor the work environment. - The sharing of knowledge. - Use specific standards such as the British Standard: PAS- 1192.	- A BIM team should be formed. - Provide the necessary communication tools. - Gradually replace the traditional teams with new one.	- The company needs an integrated BIM model. - The evaluation of the BIM product. - Adopt a national or international code.	-Persuade the management to move to BIM and provide all supporting factors. - Cooperate with the supplier and develop a method to deal with him.

1.4. Major Maturity Areas: Policies

- Preparation: Research, educational/training, and delivery programs. It came in a specific box and took the assessment 10 out of 40

• Training should be adopted on an ongoing basis and not when necessary
• Set specific strategic objectives, so that the training fructifies.
• MEP needs special attention. If the architectural and structural specialist had followed the REVIT and MEP engineer followed the AutoCAD program, the company would not be working on the second level of the BIM.
• The developing a time plan.
• Involve all parties, even those who do not work with BIM, like Quality management, and Planning.
• Innovation strategy.

- Organization: Blogs, regulations, legislation, classifications, guidelines, and standards, The rating is 0

• The researcher recommends the adoption of reliable codes such as British code.
• Evaluation for each project, is the code used for this situation?
• Need the guidance for the best methods of learning and training.
• Regarding the course, is it better to be: some long hours taught at home or class in the company.
• The development of unique records containing reports: take advantages of the recording mistakes.

- Contractual: Responsibilities, Remunerations and Risk Allocations: Also took rating 0.

• Must be done before sitting with the client and agreeing with him on the work plan.
• Method of dealing with contracts such as CIC BIM may propose to use in work within the BIM projects.

Table 3. Performance Measurement Results, Main Maturity Areas: Policies. Author results, 2017.

Performance Measurement Results			
Main Maturity Areas: Policies			
Capability set v5.0	Preparation: Research, educational / training, and delivery programs	Organization: Blogs, regulations, legislation, classifications, guidelines, and standards	Contractual: Responsibilities, Remunerations and Risk Allocations
Key maturity areas granularity level 1 and Score	Defined (b) Score: 10	Initial (a) Score: 0	Initial (a) Score: 0

Recommendations	- Ongoing training. -Set specific strategic objectives. - Provide special attention to MEP Revit courses. - Develop a time plan. - Innovation strategy.	- Adopt of reliable codes. - Provide an evaluation of each project. - Learning and training. - Recording of errors and take advantages of it later.	- Work plan. - Method of dealing with contracts such as CIC BIM

Conclusion

- Most of the public administration staff in Syria know little about the BIM. Appropriate follow-up to this research will be an analysis of their knowledge and desire to implement it in public administrations and institutions.
- Readiness and willingness to change are necessary to further develop the application of BIM in Syria and the world.
- An initial team of BIM set up to be trained with the provision of subsequent staff to support the first team and start to evaluate the performance and the reality of the company and work to move gradually towards BIM as a qualitative and individual step and with remarkable cooperation for public companies in Syria.
- The analysis of the company performance was based on the BIM Maturity Matrix, evaluation criteria are determined by specific needs of the various participants of the building process. This leads to the successful project completion and subsequent management of the lifecycle of the building [5].
- Recommendations have been made for all aspects of the so-called BIM fields of technology, processes, and policies of the organization with an aim to improve its position and pushing it towards the second level of BIM.

Acknowledgments

SGS17/121/OHK1/2T/11

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Virtual Reality Applications in Architecture: Bill of Quantities & Virtual Reality

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Abstract

As time goes on and building practices change, procedures that at one point seemed indispensable can fall by the wayside. One such example is the bill of quantities (B/Q). Research into recent literature attributes this decline in use to a multitude of reasons such as its complexity and potentially drawn-out time to produce, non-traditional procurement systems growing in popularity and the challenge of using its information in a construction schedule. With these issues in mind, a combined process of BIM, Virtual Reality and including the client in the design process has been proposed as a potential solution.

Following a literature review and precedent study, an experiment was carried out using this new process to simulate a client's design decisions on window and interior furnishings specifically. Their choices made using Virtual Reality automatically updated a B/Q Revit Schedule and allowed the client to have a firm grasp on the project costs. Not only did this process give the client more confidence in a pleasing final outcome, but the technology ensured an up-to-date, accurate and easily understood B/Q. Here lies great potential savings in cost, time and gives the B/Q a newfound importance in future construction processes.

Keywords: Virtual Reality; Bill of Quantities; BIM; Revit

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1. Introduction

A B/Q is a document introduced in Great Britain after the Industrial Revolution in the 19th century. At that time, it was put in place in order for tradesmen to pay their workers and as a fee for clients. Presently, it has evolved to specify the qualitative and quantitative aspects of every element in a proposed project. Essentially forming a record of all the items used in construction [1]. It is commonly used for estimating costs as part of the traditional procurement process and is an important part of a tender document. However, literature suggests that their use is declining due to a variety of reasons such as its complicated and time-consuming preparation, an increase of non-traditional procurement systems and difficulty incorporating its information into a real life construction schedule [2 & 3]. In relation to a client, it attempts to supply comprehensive cost information yet as a project progresses, it is common for costs to increase and the B/Q left without updating [1]. At times, this can leave a client feeling uninformed on how exactly their money is being used and the overall financial status of the project.

This study will counter this by investigating the use of BIM and Virtual Reality as a means of including the client in design decisions and creating an improved bill of quantities process. Focussing on aesthetic choices like the size and position of windows, and interior furnishings will illustrate VR's ability to improve the design process and better satisfy the client's desires. Moreover, as the client makes these choices they will have direct access to an updated B/Q and fully understand the costs involved. Using this technology aims to modernize the B/Q process and convert a potentially complex document into an accessible and interactive user experience.

2. Bill of Quantities

As pointed out previously the Bill of Quantities has been an important estimating tool used for centuries, during this time there have been many technological advancements that have improved the efficiency the B/Q and of construction estimation the introduction of CAD/CAE systems in the 1950 is one example [4]. As the construction industry once again moves forward technologically with the widespread adoption of BIM and VR systems the; use, functionality and efficiency of the B/Q should be revisited. The B/Q is still widely used particularly in traditionally procured schemes, where it not only provides cost estimates for clients but also forms part of the tender document, used by speculative contractors to price, programme and bid for a potential contract [1]. In recent years, however, the amount of traditionally procured construction contracts has been declining in favour of more modern systems such as; design and build or management contracting, which often forgo the need of a B/Q. These procurement systems have several benefits over Traditional procurement such as condensing the tender and design phase, while also reducing client financial risk. The tender is condensed in modern procurement methods, in part by removing the need to prepare a B/Q which is often a lengthy and onerous process [5]. Modern procurement methods can also give a client a degree of cost certainty which is not possible with traditional procurement [5] this is usually achieved - such as in Design and Build – by giving the contractor more control over the design of a project, while also creating more liability for the contractor when a project's costs overrun. Modern procurement methods are not suitable for all projects however, particularly in smaller one-off projects where control over the design is more important. The RIBA plan of work 2013 overview points out that the traditional contract route remains by far the most dominant form of procurement. Therefore, the production and quality of the B/Q must continue to be refined as it is vital to the traditional procurement system.

If a B/Q is of poor quality, it can seriously undermine the validity of a tender and lead to inaccurate estimates, higher margins in bids, claims and disputes [6]. This means that a bill of B/Q is typically produced by a trained quantity surveyor who bases the document on specifications and drawings produced by the architect [2]. This highlights one of the major issues that can lead to a poor-quality B/Q; Architect's drawings. As the B/Q is directly derived from architect's schedules and drawings, the document is vulnerable to client's oversight or misunderstanding of elements presented within these schedules and drawings such as; interior finishes, carpentry and ironmongery. These oversights and misunderstandings generally need to be rectified later and are often only caught after construction has begun, which leads to rework and increased costs. This issue is described by Li and Love: "A significant number of rework in construction is caused by client last minute changes and their inability to acquire a realistic appreciation of the product from the 2-D drawings at the design stage" [7]. If a client cannot grasp a realistic appreciation of the -typically- 2-D drawings and schedules produced by architect (which is what the B/Q is based upon) prior to the tender stage, the accuracy of the B/Q is undermined even before it has been created. Therefore, the accuracy of a B/Q can be improved by helping the client understand what is actually in that document [7]. Li and Love proposed a solution for this issue, which they believe is caused by the presentation of a buildings design in 2D format. They created a 3D visualisation system that allowed clients to 'walkthrough' a design so that they could get a;

"virtually real appreciation of the interior layout and its architectural details" [7]. This allowed clients to suggest changes to the design before it was 'quantified' into a B/Q. This improved the accuracy of the B/Q as it accurately reflected the client's aspirations for the project, it also prevented any 'last-minute' client changes that could have incurred extra cost. While the 'walkthrough' provided significant benefits over the standard 2D architectural drawings, Li and Love concluded by suggesting that immersing a client in a VR environment might allow for an even more accurate reflection of a client's aspirations which would also improve the accuracy of the B/Q. This in would be possible, by giving the client an appreciation of a design similar to the way they experience buildings in real life, negating the need for them to 'acquire a realistic appreciation' of a design through 2D drawings.

3. Development Strategy

In order to create this prototype, the group broke down its development into several stages: creating the BIM model and B/Q, converting the model into VR, designing and building in VR, interactive design presentation and a precedent study. First, the BIM model. The model being used is a private housing design that was created in Revit as part of a past project. This was deemed well suited to our prototype because the typology offers a closer and more involved relationship between architect and client.. A lot of care is placed on finding the client's preferred furnishings and exact detailing to perfect their home and VR can be very useful in this situation. Moreover, each of these design decisions can greatly alter the, generally speaking, smaller budget of most residential projects therefore giving the bill of quantities a heightened importance. The window types and furnishings used in the prototype were created by researching contractor's building information and manufacturer Revit packs respectively. The information from the chosen architectural element is then automatically included into a Revit schedule which calculates pricings.

To transfer the model into VR, various methods were considered. As [8] explain, a common workflow is completing your model in Revit, converting into another separate graphing software, like 3Ds Max, and then finally load that FBX file into a gaming engine such as Unreal or Stingray. It has also been noted by the writers that during this complex and time-consuming process it is common for information to be lost. Furthermore, there is no synchronization with updated models [9] meaning if the design was updated in Revit, the whole process has to be repeated.

After comparing the different programs and methods available to the group, it was decided that the plugin Enscape would be the most effective. The chosen plugin works directly with programs like Revit in order to create real-time and fully navigable VR [10]. It only takes mere minutes to translate drawing data to VR with generally no information lost and with only a click of a button. This fully resolves the previously mentioned issues of time and complexity. In addition, in regards to the synchronisation problem mentioned above, Enscape proved itself as particularly apt. If there were any changes made to the linked Revit model, the live VR model will automatically be updated. In a client meeting, this has the potential to give clients a better understanding of the changes they desire and leaves no surprises as the project moves to construction. Enscape offers the client a true, life-like and dynamic imitation of a planned space that is much easier to understand than an abstracted 2D drawing.

The presentation is an important part of the architectural process. Presenting to a client should be clear and a smooth flowing representation of the design solution is necessary in order to gain approval and maintain the client's confidence. Using a variety of different software here is the solution. Combining Revit for modelling and Enscape for visualisation, the design team are able to make changes in real time and makes the work easy to understand for the clients. Enscape simply updates the design changes allowing you to demonstrate to the client how the project looks and how different objects sit in the space. This inspiring presentation tool offers immediate implementation into a workflow and can save time and money.

The final stage of the development strategy was to perform a precedent study on the currently available programs that the group could look to for guidance. However, it was soon clear to see that the current applications were limited in their scope. For example, the IKEA showroom demonstrates to the client what products from their catalogue look like and how they fit into a room on a VR 360 degree camera orientation, although this is not to the client's room specification or showing the price of each item [11]. Zerolight and Design Milk showrooms for Audi and Cadillac provide the clients with full customization of the vehicles and is the most detailed VR application, but again does not provide the client with the price break down of each part [12&13]. The applications all seem to provide an incomplete service that could be improved for a better client experience. VR showrooms should offer strong visuals showing what the client is buying and variations on the item in different environments, colours and sizes, while also providing the client with accurate pricing. This paper will now proceed to describe the prototype and the process of achieving this.

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4. Prototype

During the development strategy key stages in the prototype development were identified as detailed in Chapter 3. The client will then gain a better understanding of the design and help them perceive what they require for their build. The BIM model itself was designed as a new two storey detached house which can be utilised to suit the clients requirements within the manufacturers catalogue. Within our prototype the catalogue that we based our internal furnishings on was IKEA; this allowed us to generate 3D models directly from IKEA's catalogue and then import them into Revit. There was a different process for modelling the windows; instead of a catalogue they were generated based on manufacturers specifications [14]. This meant that all BIM information needed to be obtained from the manufacturers website and developed into specific window types for use in the model [15]. We merged our Revit prototype into Enscape, which allowed us to do testing within the VR. Enscape can also be used to spectate what the VR headset user is seeing but in real tray rendering which provides the Architect with a visual input for what the client is looking at and can refer to when discussing design revision.

The prototype model was designed with rooms such as the living room, dining room and bedroom to test the development strategy by placing windows and furniture at specified positions. Both testers acted the role of the Architect and client however there were many errors before reaching this stage. The Oculus software proved to be an issue; the software was bugged and wouldn't allow VR use, however after several tries this was no longer the case and the VR was usable. Once access to the model was obtained, the movement speed of the controller needed to be adjusted as it was too fast and gave the tester motion sickness. The height of the user also needed scaled to the model. Otherwise the movement around the room was deemed sufficiently accurate and testing could commence. The testers then had access to OBS - a recording software - which then put layers on top of each other in real time and began recording results, firstly testing with the group members and then with another participant. There were many takes as the recording crashed when altering some types of furniture.

During testing we gathered data revolved around three rooms within the prototype, the living room which was focused on furniture and windows, whereas the dining room and bedroom just had the furniture. These rooms were set up with standard furniture at first to provide the feel of scale in the room. From this the client can add, remove or alter the placed furniture within the chosen room which will update and change on the custom-made B/Q schedule. All the furniture and windows within the test rooms refer to the B/Q schedule which is updated live when something is added or removed.

Figure 1 - Revit model immersed in VR

The living room test consisted of altering the window widths and heights to the clients requirements whilst using the VR headset and receiving live updates from the Architect. The furniture was also altered by the Architect upon the client's request. The elements within a single item of furniture that can be altered are the texture, colour, size and style. The amendments processed by the client within the VR are transferred to a custom-made B/Q schedule which can be seen in figures 2 & 3.

Window Schedule							
Type	Count	Level	Manufacturer	Width	Height	Cost	Comments
Circle Window - 600mm Diameter	1	00 Floor Level	Glass Tops	600		£70.00	
Circle Window - 900mm Diameter	1	00 Floor Level	Glass Tops	900		£80.00	
Sash Window - 900 x 1200mm	1	00 Floor Level	Glass Tops	900	1200	£1140.00	
Sash Window (Vintage) - 850x1850mm	4	00 Floor Level	Jeld Wen Windows & Doors	850	1850	£5400.00	
Sash Window (Vintage) - 1000x1850mm	6	00 Floor Level	Jeld Wen Windows & Doors	1000	1850	£9420.00	
Grand total						£16110.00	

Figure 2 - Window schedule

Furniture Schedule (Living Room)						
Room: Department	Type	Description	Manufacturer	Count	Cost	Comments
Living Room	Lampan Lamp	(B) 130 x (W) 400 x (H) 290	IKEA	2	£32.00	
Living Room	Coffee Table	(L) 550 x (W) 550 x (H) 450	IKEA	2	£50.00	
Living Room	Shelving Uint	(W) 388 x (L) 1500 x (H) 803	IKEA	1	£40.00	
Living Room	Low Lounge Table	(W) 900 x (L) 1800 x (H) 450	IKEA	1	£75.00	
Living Room	Branco TV Stand	(W) 400 x (L) 1200 x (H) 480	IKEA	1	£105.00	
Living Room	Bench Sofa	(W) 660 x (L) 1830 x (H) 800	IKEA	2	£420.00	
Living Room	Plasma TV	50"	IKEA	1	£500.00	
Grand total					£1222.00	

Figure 3 - Living room furniture schedule

The test for the dining room involved adding, removing and altering furniture from the catalogue to the model, as per client instructions as seen in figure 4. The combination with the client being immersed while the architect can live update is bridging the gap where Architects have been wanting to cross. These tests show that it is possible to cross this bridge and get more benefits from it in return with example a more accurate B/Q and the clients direct sign off for progression to the next stages. With any furnishings required as seen in figure 5 the B/Q can be flexible to illustrate more variations in case the budget is an issue for the client

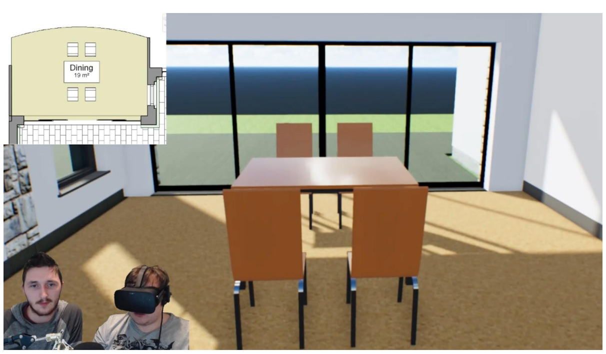

Figure 4 - The prototype tests showing changes in furniture.

Figure 5 - The participant making changes within VR

5. Conclusion

Overall the results of this prototype had very few issues in terms of the software being used. The findings we encountered through the process included a smooth transition from BIM to VR. Overall it was easily imported from Revit into Enscape, the software we used for the prototype only required a plugin for Revit. The main issues we encountered were the setup of the Oculus Software due to the quantity of softwares used to setup the presentation -, Revit and Enscape along with the Oculus software itself. A participant for the prototype was used to try the experiment out themselves and this identified issues to be addressed. These included the height of the tester and the movement speed of the controller. The client can gain a more realistic appreciation for the design before it is priced as they can get a new perspective of the structure seeing it in VR. In a normal plan a client could get confused due to miscommunication therefore VR is the way forward for allowing the client to understand the design.

There are many improvements that can still be made to this method before it can be considered a gold-standard. Firstly, there could be a better integration strategy brought forward in terms of allowing the client to see the B/Q within the VR. This would allow the client to see the costing within the headset therefore being unable to understand the cost of each change. Right now we are able to make changes in live time however that is done solely through Revit and through the Architect. In future this could be adapted so that the client can have some or all control in terms of positioning and the Architect. Another possible development that could enhance the experience is breaking down the B/Q to a more simplistic form so the client can understand it better. In an attempt at this we broke down the schedules to windows and furniture separately and within each room instead of a full overall cost. A further improvement to this would be the update in window size costs incorporating the construction as well as the component prices.

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