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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

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]

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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.

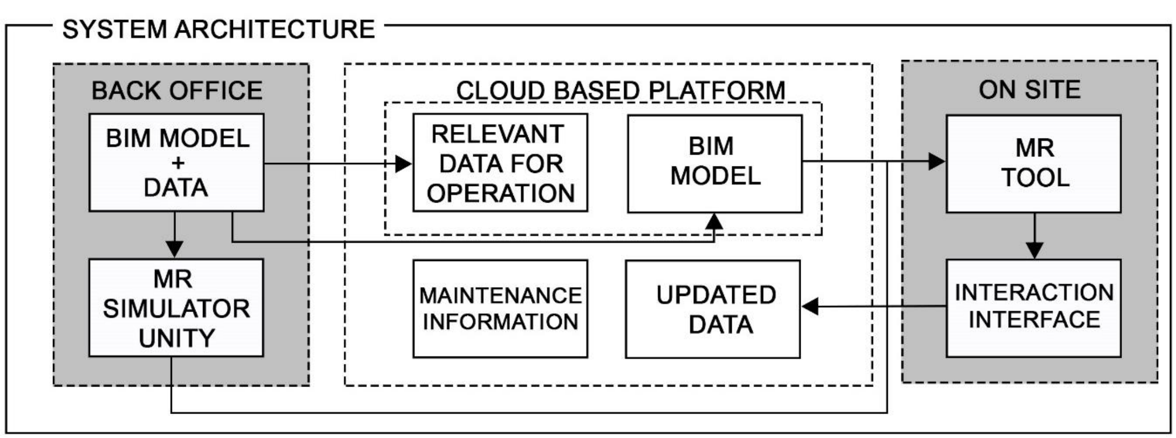

Fig. 1. System architecture

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.

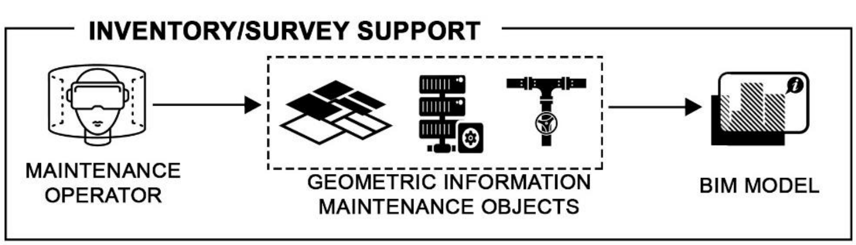

Fig. 2. Inventory/survey support

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.

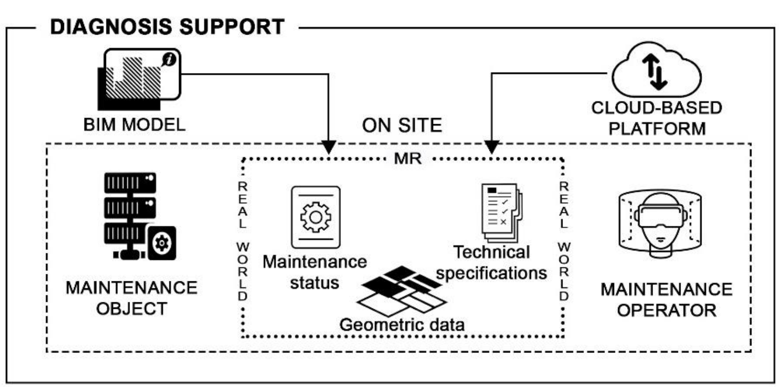

Fig. 3. Diagnosis support

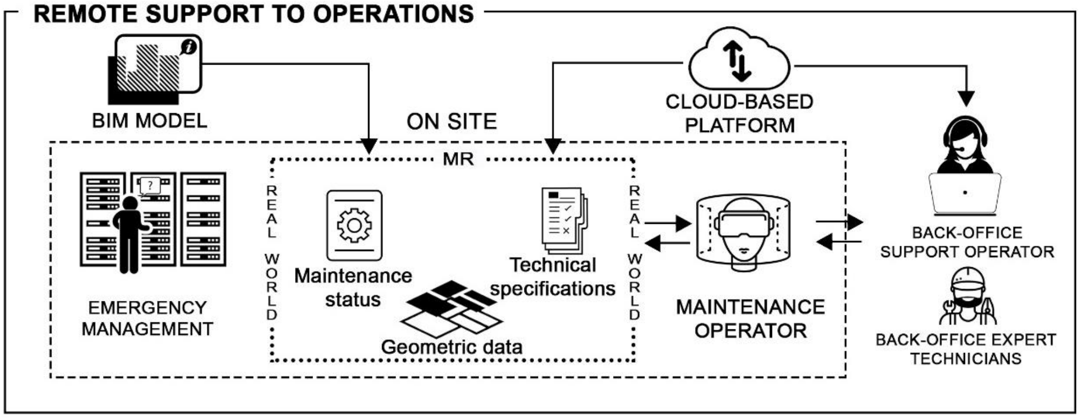

Fig. 4. Remote support to operations

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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