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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.

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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

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.

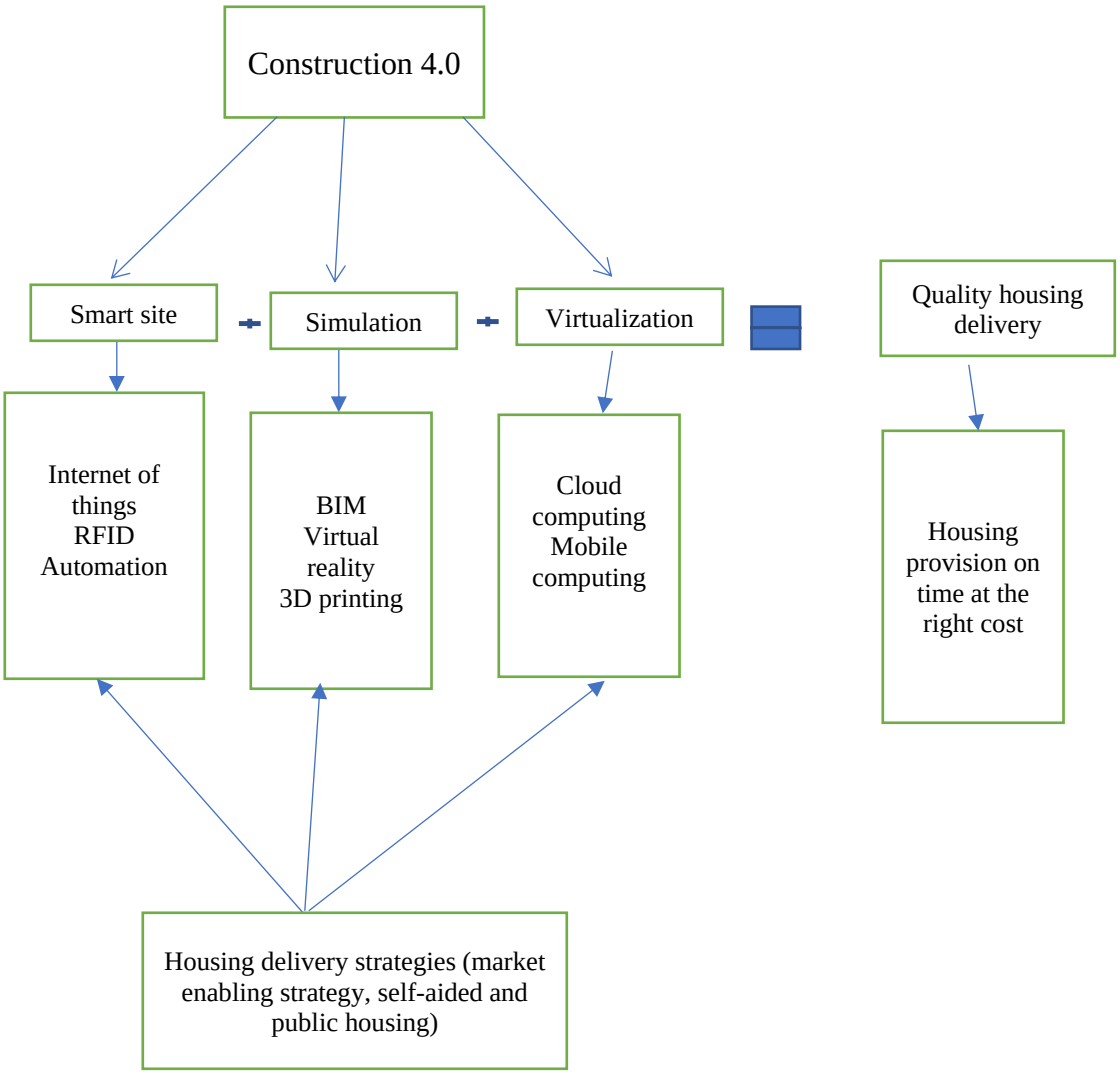

Figure 1; Conceptual framework
Source; Adapted from Aigbavboa [18], Mahamood and Akinlabi [36], Osunsanmi et al. [14]

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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