Exploring the Protocol for Construction 4.0 Use in South

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Abstract. The reported study is about developing a protocol for enabling Construction 4.0 in South Africa by utilising appropriate digital technologies. The scoping review methodology was used to compile the paper. The findings of the related literature review indicated a lack of case studies to authenticate and provide a pathway on how to best implement digital technologies to enable Construction 4.0 in South Africa. The general conclusions showed that there is less literature that can test the various technologies empirically which can be used to transform the construction sector to a fully digitised sector. There is no guidance on the way to proceed when intending to implement digital technologies to digitise the local construction sector, given the chronic challenge of excessive time overruns on projects. The findings indicate a need for the formulation of a protocol aimed at digital transformation in South African construction. These findings thus reinforced the need to empirically test the available digital technologies in South Africa on whether they are best suited to enable a transformation, which will promote favourable project delivery outcomes.

Keywords: Construction 4.0 · Digitization · Transformation · Project delivery · South Africa

1 Introduction

The local construction sector is projected to grow towards an upward trajectory, along with the level of project-related risk. The diverse nature of construction related projects has increased pressure on construction companies to preserve their financial solvency in relation to their forecasted growth in the modern market segment. The primary purpose of the research will be to try to ascertain how digital technologies can enable Construction 4.0 in so far as ensuring construction companies can undertake construction projects in a more effective manner. The South African economy has the construction sector as the fourth most significant sector in terms of contribution to the gross domestic product (GDP) [19]. Construction projects are technically challenging, prone to significant risk, physically and physio-logically demanding undertakings that are frequently implemented and delivered by participants with varying cultural differences, backgrounds, political systems, and languages [26] In addition, digital progress has

C. Aigbavboa et al. (Eds.): CIDB 2022, pp. 143–152, 2023.
https://doi.org/10.1007/978-3-031-22434-8_15

impacted all industries, leading in a new technological era now known as the Fourth Industrial Revolution (4IR). This new technological era is satisfying consumer demand for better ways of doing things. Innovation has led the charge on improved productivity and sustainability, and redefined the skills, the roles and responsibilities and competencies required to achieve success (World Economic Forum, 2020). Multiple innovative digital construction technologies are available to the construction sector to enhance practicality and functionality of the site based activities, resulting in overall improvement of the performance of construction companies. Furthermore, the Diffusion of Innovation theory suggests that majority of these technologies, their adoption in the construction sector has been poor as is the case of many developing economies, such as South Africa. This low adoption rate, results in low productivity of the sector being prevalent.

4IR has seen the emergence of Industry 4.0. Industry 4.0 resulted in the emergence of the term Construction 4.0. Construction 4.0 is modelled directly of the concept of Industry 4.0; the principle of Construction 4.0 is shaped on the basis of integration of various tools and technologies (both in the digital and physical layers) that provide the ecosystem platform from which the built environment assets are designed and executed. Construction 4.0 can also be interpreted more directly as the innovation of numerous construction management tools and techniques, driven by Industry 4.0 emerging technologies, that enables for a possible emergence of a truly construction site that is regarded as 'smart'. Construction 4.0 can also be implemented as an activity of the application of cyber (digital and cloud-based)—physical (site) systems which enable a digital transformation of the local sector intended for the sole purpose of attaining maximum project performance of the sector. Lastly, Construction 4.0 can be explained as the integration of cyber-physical digital technologies that support a digital construction site, digital modelling (Building Information Modelling (BIM); Digital Twin (DT)), simulation, and virtualization. So far, there is no specific Construction 4.0 model applicable to the South African construction sector. In enabling Construction 4.0 in South Africa, digital technologies would assist to solve the problem of excessive schedule overruns on projects which often also translates to cost overruns and poor-quality issues on project delivery.

Scholars also note several challenges in the local adoption of digital innovative technologies. Sawhey et al. [25] state the emergence of the Fourth Industrial Revolution (4IR) has resulted in a set of particular frameworks of Industry 4.0, the construction sector also could leapfrog to more efficiency in terms of improved project and business performance. Such a transformation can be a reality by the emerging of existing digital and newly introduced digital technologies forming part of the paradigm that is Industry 4.0 (Osterreich & Teutenberg 2016).

The growing rates of digitisation and the enhanced pace of technology adoption could potentially be a source of an augmented lift to South Africa's economic prosperity in the not too distant future [21]. A recent study scrutinised the economic performance of seventy-one (71) economies in the developing world in the last half century. The study identified from those developing economies eighteen (18) outperformers that had a consistent growth in terms of GDP over decades. Those countries from the developing world provide valuable economic lessons for South Africa. These developing countries that have been identified as outperformers economically have a pro-growth agenda of income, demand and productivity. As a central-component of that pro-growth agenda,

they have fostered companies that are highly productive and also enabled for industries that are highly competitive. Utilising technology to greatly improve the level of innovation and project productivity, South Africa could emulate these economies. Thus, the objective of this review paper is to highlight the need for a set of guidelines in the form of a protocol that will establish a system of rules that explain the correct conduct, practises, and procedures in the formal enablement of Construction 4.0.

2 Literature Review on Construction 4.0 in South Africa

2.1 Scoping Review

In this section, a breakdown of the literature was reviewed, and the literature led to the identification of knowledge gaps that includes lack of adoption of digital technologies for enabling Construction 4.0. This literature reviewed was important to further identify publications related to the use of digital technologies to enable Construction 4.0 in South Africa over a 16-year period. The main keywords that were used in this paper were: Construction 4.0, Digitization, Transformation, Project Delivery, South Africa. Several scholarly databases were explored, such as Google scholar, EBSCO, Science Direct and Emerald to be precise. About one-hundred and thirteen (113) published papers were searched, comprising of conference papers and journals. The number was later refined based on appropriate titles and abstract, whereby several thirty-three (33) papers were of interest. To make it a point that the titles and abstract fit this survey all the papers retrieved were manually explored and analysed. Therefore, a conclusion of this study's investigation was that research on the "use of digital technologies to enable construction 4.0" topic over the last 16 years has been increasing as indicated. Only those papers deemed relevant to the subject matter were read, scrutinized and analysed further. This assisted with the identification of trends key interest areas that were covered by numerous papers, namely: 'Barriers to use of digital technologies, Assessment of stakeholders' inclination in the adoption of construction 4.0 technologies, Digital technology transformation, The use of digital twins for enabling construction 4.0, The utilization of 3DP for the enablement of construction 4.0, The usage of BIM for the formal enablement of construction 4.0', which represented the research scope within the 'construction 4.0' topic. The papers were classified according to the years. This classification shows that most of the research on Construction 4.0 was done in 2020 (18 papers) followed by 2021(11 papers) and lastly in 2018 (8). This is an indication that research on the usage of digital technologies to enable construction 4.0 has been increasing over the years and there is more exposure and understating around this space. However, it could indicate that the literature collected in this study could be limited. The continued exploration and findings around Construction 4.0 is a key mitigation strategy to avoid underutilisation of these technologies.

2.2 Opportunities Offered by Digital Technologies to Enable Construction 4.0

There are multiple well-known projects in South Africa that have suffered from the crippling challenge of severe time-overruns. The well documented Eskom projects, Medupi

and Kusile power stations are but some of these projects (Tshidavhu and Khatleli 2020). A megaproject can be explained as an endeavor exceeding $1 billion United States Dollars (USD) (Flyvbjerg 2014). Practically, schedule overruns are a hallmark in megaprojects implementation (Aljohani et al. 2017). Megaprojects are very costly, they can be inclusive of numerous technical and contractual risk factors that can result in significant project delays or ultimately significant technical failures during the project's execution (Ma et al. 2017). The construction sector is notorious for its slowness to adapt, and traditional practices remain the most-used project delivery methods (Fulford and Standing 2014; Ahiaga-Dagbui et al. 2015). Innovative technologies, on the other side of the spectrum are not adopted fully by these companies. There are multiple digital innovative technologies accessible on the sector which focus on the improvement in the practicality and technicality of site-based activities and to enhance the construction project performance of local construction companies.

Abimbola [2] states that research conducted indicates that there are opportunities for the transformation of the construction sector towards Construction 4.0 and thereby increasing the sectors overall performance. Oke et al. [28] highlighted numerous barriers hampering the adoption of digital technologies. Majority of the role players have limited to no knowledge of their capabilities in terms of improving projects' productivity. Abimbola [2] indicates that there are various available digital technologies, offering an abundance of opportunities in improving historical challenges within the sector. This transformation has been widely accepted to be the blueprint for the Construction 4.0 framework. However, there are no clear guidelines on how this transformation can be smoothly implemented as there is no clear guideline or policy to aid implementation.

Gartner (2017) elaborates that the Framework for Construction 4.0 uses Cyber-Physical System (CPS) at its centre and links with a hub housing digital tools to create a digital ecosystem. This ecosystem is where independent cohorts of digital enterprises and role players can share integrated digital platforms for mutually beneficial purposes, improved project, and business performance. Sawhney et al. [25] mention that the Construction 4.0 framework is dependent on an integration of various digital tools and technologies (both in the digital and physical layers) where the Construction 4.0 framework is seen as a guide in terms of how projects are to be designed, executed, and managed. The protocol would assist in the identification of specific digital tools within the digital layer and how they could pair up with digital technologies on construction sites such as Augmented Manufacturing (3DP) to enable a digitized construction site.

3 Methodology

The sector has been slow to reap on numerous opportunities that technology and the progress in the availability of project data resulting in improved project performance, the uniformity and guarantee in terms of the quality of the project and business outputs. In spite of several historical attempts to augment a digital transformation, the sector currently has persistent shortcomings such as fragmentation in the process, ineffectiveness relating to flow of project information, and the role players working collaboratively. Therefore, the study is aimed at assessing the level of effectiveness of the introduction of a set of protocol guidelines which provide a guideline on best practises during implementation.

The methodology followed for this research is based on a narrative literature review. Onwuegbuzie et al. [29] describes a narrative literature review as an unbiased dissection, thorough, analytical evaluation of the existing knowledge on a subject matter. They are integral research components in the research process and assist in the drafting of a theoretical framework. Narrative literature review can be sub-divided into four areas being the following: general literature review, theoretical literature review, methodological literature review and historical literature review. For purposes of this research project, methodological literature review was chosen. Onwuegbuzie et al. [29] describes methodological review is defined as where the methods and design relative to the type of research are outlined. These reviews narrate the positives and negatives of the methods chosen and present possible orientation. This was the method best suited to identifying how the set of protocol guidelines can best be utilized in utilizing digital technologies for implementation of Construction 4.0 in South Africa.

4 Findings and Discussion

In reviewing the available literature using the methodological literature review approach, it was found that there is a strong willingness within the sector in the adoption of Construction 4.0. However, barriers to adoption are several as listed below on Table 1. Only the top ten (10) barriers were identified from the literature and grouped into order of importance or order based on a support by analyzed articles.

From the above findings it can be argued that that there is a need for the development of a protocol that forms a system of rules that explain the correct conduct, practises, and procedures in the formal enablement of Construction 4.0. The focus of the research is because within all these barriers, what can be ascertained is that there is no clear and concise way to implement digital technologies as identified within the three most-commonly referenced Construction 4.0 models as listed under Table 2. This is supported by the high ranking of three barriers; The Lack of standards on how to implement (15 papers), Legal and Contractual uncertainty (11 papers) and Regulatory Compliance 11 (papers). El Jazzar et al. [13] endorses the findings by mentioning that the implementation barriers identified in the enablement of a digitised sector, being the absence of global standards and associated guiding model or framework for implementation is a major blockade.

Osunsami et al. [32] in a recent research project of investigating the preparedness of role players in adopting technologies driven by Construction 4.0 supports the findings in this paper by also concluding that there is a strong drive to enable construction 4.0 among construction role players. The likelihood of a fusion of construction 4.0 principles is still relatively low. The basis of our research is that with the formulation of a set of protocols which will guide adoption of digital technologies to implement Construction 4.0 provides us with a gap in knowledge which can further be investigated. However, there needs to be a clear pathway looking at the South African context on how the digital layer will interact with the physical layer, which is what is currently missing. There are existing frameworks that could aid in this regard as presented in Table 2, however not all the digital technologies will be applicable. How the identified technologies will interact with each other needs to be supported by a clear set of guidelines which will assist to achieve, adopt and implement Construction 4.0.

Table 1. Implementation barriers: Construction 4.0

Barriers to implementation of construction 4.0		
Barriers	Descriptions	Sources and/or key references
Implementation challenges	1. High implementation costs	[1–12, 14, 15, 17, 19, 20]
	2. Low investments in Research and development (R&D)	[2, 3, 5–7, 9, 10, 12, 13, 15–20]
	3. Need for enhanced skills	[1, 2, 4–9, 11–15, 17]
	4. Longitudinal fragmentation	[3–9, 11, 12, 14, 15, 20]
	5. Lack of standards	[1–5, 8–12, 14 17, 19, 20]
	6. Data security. Data protection and cybersecurity	[1–11, 16, 19]
	7. Legal and contractual uncertainty	[1, 2, 4, 5, 7–12, 14, 19]
	8. Regulatory compliance	[1–3, 6–12, 19, 20]
	9. Fragmented industry structure	[1–3, 6–12, 19, 20]

References in the table above are as follows; 1 = El Jazzar et al. [13]; 2 = Sawhney et al. [25] 3 = Osunsami et al. [32]; 4 = Hossain et al. [15]; 5 = Oesterreich et al. [27]; 6 = Cooper et al. (2018); 7 = Dallasega et al. [12]; 8 = Alaloul et al. [3]; 9 = Klinc et al. [18] 10 = Munoz-La-Rivera et al. (2020); 11 = Prieto (2021); 12 = Ibrahim et al. (2019); 13 = Craveiro et al. (2019); 14 = Oke et al. [28]; 15 = Chowdhury et al. (2019); 16 = Aigbavboa et al. [26]; 17 = Taher (2021); 18 = Forcael et al. (2020); 19 = Windapo (2021); 20 = Osunsami et al. [32]

5 Gaps in Knowledge

Construction 4.0 can resolve the inherent problems experienced by construction projects as it can improve the productivity. Osunsanmi et al. [32] state that despite the numerous values offered by innovative technologies in industry 4.0, up to this point the sector has been unable to realise all the possible advantages and potentially challenge the other sectors such as manufacturing which has commenced reaping the rewards due to the peculiar characteristics of the industry.

In the different stages of the project lifecycle consisting of planning, design, execution, and management, there is room for innovation to be further investigated. This therefore calls for adaptions of innovation during each stage of the lifecycle, but with emphasis on stages of design and construction on how they can enable Construction 4.0. The importance of enabling Construction 4.0 through innovative digital technologies has been well established in the reviews of the pieces of key literature (Sawhney et al., [25], El Jazzar et al., [13], Munoz-La-Rivera et al., 2020, Osunsanmi et al. [30], Manzares et al., 2020, Prieto., 2021, Hatoum., 2021). The issue is which of these proposed digital technologies will best be suited to a local context by overcoming digital collaboration bottlenecks in the construction industry [28]. Adequate proof exists to support that adopting digital technologies will enable Construction 4.0 in developed countries

(Perrier et al., 2019). The state of affairs is adverse in developing nations as there is no tangible evidence relating to the transformation in terms of utilising digital technologies in the sector [22]. The key to a digital transformation that seeks to enhance project performance is embedded in comprehension of the project related risks involved is important [2]. Without undertaking empirical research in the field and analysing current projects, it will be difficult to know which of the available digital technologies will be able to override the local challenges in the sector.

The implementation barriers that have been established in this research as well as other referenced material, it's clear not all the listed digital technologies will best serve the case of South Africa to transform the sector from traditional methods to Construction 4.0, hence there is a need to identify only those digital technologies that can best assist to transform our local construction sector to achieve Construction 4.0 by forming the basis of a set of guideline protocols to be developed to ensure a successful attainment of the enablement of Construction 4.0.

6 Basis for the Formulation of a Protocol for Construction 4.0

The importance of why the sector requires a transformation from traditional construction to Construction 4.0 has been well established in the following pieces of literature (El Jazzar et al. [13], Sawhey et al. [25], Prieto. 2021, Ibrahim et al. 2019, Craveiro et al. 2019 and Munoz-La-Rivera et al. 2020). The concept of Construction 4.0 developed from the urgent requirement for the sector to simplify the fragmentation and to approach the necessary attainments required in the industry. Ibrahim et al. (2019) state that technology inline with the Industrial Revolution 4.0 is gradually improving, the sector is facing more futuristic and complex design requirements, green building, smart home and diversity of material, which necessitates for the construction role players to transform from conventional practices to leverage more on digital and modern technology. Craveiro et al. (2019) supports this by stating that this transformation, which by analogy to manufacturing has been termed as Construction 4.0, will assist construction companies to improve effectiveness in terms of increased productivity, reduction in project delays and budget overruns and improved safety, quality, and resource-efficiency. The transformation of the sector is crucial as several emerging economies have achieved strong growth by leveraging on digital technologies to improve project performance and innovation, South Africa can emulate these economies (Mickinsey 2019).

In transforming the local sector to Construction 4.0, the use of digital innovative technologies is paramount. However, in the review of preliminary literature there seems to a contrast in various arguments, theories, methodologies, and approaches in the literature, regarding how best to transition from conventional to digital construction. One of the differences identified, is which of the available digital technologies would best be suited to make this transition in South Africa. There are three (3) models widely discussed around the field of Construction 4.0. These three models are coherently different from each other. The comparison of the three models is shown below in Table 2, also shown are the digital technologies within each layer.

All the three models listed presented below were analysed based on available literature and the results were utilised to provide inputs into the proposed protocol to be developed which will be tested on current construction projects.

Table 2. Available construction 4.0 models

	Construction 4.0 models		
Model type	3-layer transformational trend model	3-layer approach model	4-layer implementation model
Authors	Sawhney et al.[25],	Munoz-La-Rivera *et al.*(2020)	El Jazzar et al.[13],
Layers within each model	1. Digital layer, 2. Digital tools and 3. Physical layer	1. Building information modelling (BIM), 2. Lean construction (LC) and 3. Integrated project delivery (IPD)	1. Construction 4.0 technologies 2. Construction 4.0 lifecycle 3. Construction 4.0 integration and 4. Construction 4.0 requirements
Digital technologies	12 digital technologies listed	39 digital technologies listed	7 digital technologies listed

7 Conclusions

The implementation of digital technologies to enable Construction 4.0 is a necessity to achieve maximum project effectiveness. The study highlighted the barriers involved when attempting to use digital technologies for enabling Construction 4.0 in the local sector. The findings of the study conclude that due to the inefficiency or non-existence of regulatory compliance, legal and contractual compliance, a lack of standards and adequate infrastructure. There is little guidance or technical know-how in how to best implement the available digital technologies to enable Construction 4.0 in South Africa.

In conclusion, the study recommends that since there may be a lack of sufficient digital infrastructure locally as compared to the developed world to adopt Construction 4.0 successfully only specific digital technologies form part of the proposed protocol design. The research study serves as a basis for future research projects intending to advance a specific model or frameworks purely aimed at utilising specific digital technologies to enable Construction 4.0 because of the inability of South Africa to adequately support a full digital technology interoperability ecosystem as presented in the existing Construction 4.0 frameworks for developed nations. Lastly, the study serves as a contribution to the enablement of Construction 4.0 in South Africa.

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