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Exploring the Role of Digitalisation and Technology Uptake in the Construction Industry: Lessons from Johannesburg, South Africa

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1 ABSTRACT

Businesses within the retailing, banking, and manufacturing sectors have quickly realised and adjusted to digitisation and information technology because they can ensure efficiency and have competitive advantages. The construction industry is yet to fully enjoy the benefits that the above mentioned industries have enjoyed because the adoption of the technology is currently in the early stages with a major focus on the utilization of software. It is imperative that we achieve global sustainability by using every resource at our disposal in an efficient manner which also preserves the environment. South Africa is experiencing challenges with resource wastage, pollution, rising unemployment, housing backlogs, project delays, and financial shortages to name a few. Can digitalisation help remedy these challenges? This research endeavours to investigate the role of Construction 4.0 in South Africa's construction industry. The research objectives specifically focus on highlighting the stages and ways of applying Construction 4.0 technologies in South Africa; assessing the advantages and disadvantages of using Construction 4.0 technologies in South Africa and lastly, proposing a viable scheme for the utilisation of Construction 4.0 technologies in ways that ensure the sustainable development of South Africa. The work utilised a case study research design and is qualitative in nature. Both primary and secondary sources were used during data collection. Sixteen interviewees were chosen by homogeneous sampling and snowball sampling. The interview transcripts were analysed by categorical aggregation and content analysis. Findings reveal that digital technologies are mostly used during the design or engineering, construction, and pre-design phases but they are seldom used during operation and maintenance. It was revealed that some of the advantages of using Construction 4.0 technologies include productivity improvement, flexibility enhancements, business safety, and better customer services. The disadvantages of using Construction 4.0 technologies include implementation cost, technology acceptance, and high knowledge requirements. The benefits of Construction 4.0 exceed its challenges. Construction 4.0 is a worthy endeavour when humans are open minded, well trained to use the technology and the technology is not expected to replace them. It was however revealed that South Africa has not yet fully digitalised its construction industry and as a result, has not fully experienced the rewards of construction digitalisation. In conclusion, the researchers recommend the full adoption of Construction 4.0 and an extra effort from academics and construction specialists to create awareness so as to improve the country's sustainable development.

Keywords: Construction 4.0, Industry 4.0, Digitisation, Digitalisation, Sustainability, Sustainable development

2 INTRODUCTION

The construction industry was late to the tea party where the beneficial nature of information technology was discussed. Industries such as retailing, banking, and manufacturing were quick to see that digitisation and information technology can ensure efficiency and competitive advantages (Ikuabe et al., 2020, March). The construction industry is yet to completely enjoy the benefits that the above mentioned industries have enjoyed because Information and Communications Technology (ICT) is currently in the early stages with a major focus on the utilization of software (Osunsanmi et al., 2018). The fight to achieve global sustainable development is a great fight and one worth winning (Osburg and Lohrmann, 2017). Over the years, many countries, South Africa included, have joined the sustainability bandwagon so as to ensure that the earth's resources are being used in a manner that benefits both the current and future generations. South Africa has experienced challenges with resource wastage, pollution, rising unemployment, housing backlogs, project delays, and financial shortages to name a few (Ikuabe et al., 2020, March and Osunsanmi et al., 2018). There are multiple remedies to the above mentioned issues but the question is, is digitalisation one of them? This research endeavor seeks to find out whether or not the advantages of Construction 4.0 technologies outweigh its disadvantages. This manuscript starts by presenting the introduction and conceptual framework which

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illustrate that South Africa's construction sector is in need of a technology boost so as to create a better future for the country. The paper goes on to briefly discuss how the study was conducted in the research methodology, presents the findings, and concludes by summarizing the findings and recommending a future course of action.

3 CONCEPTUAL FRAMEWORK

One of the least digitalised industries known to mankind is that of construction. However, over the last decade there has been an increase in the need for waste reduction and an improvement of performance and productivity in the construction sector, resulting in a call for fresh innovative technologies. Both globally and locally, the construction process is being transformed by the latest digital technologies (Finsrud and Kristing, 2021). South Africa is gearing towards digitalization as it is vital for the success of large construction projects such as those that can be found in its biggest city, Johannesburg. Construction projects in Johannesburg are experiencing an increase in the use of Information Technology (IT) throughout some stages of the construction process to save time, resources and maximise productivity (Osunsanmi et al., 2018). It is important to mention that there is a difference between digitisation and digitalisation, and that without digitisation we cannot have digitalisation and digital transformation. The process of converting analogue items such as pictures, documents or sounds into digital files is what we call digitisation (Aji et al., 2021). Digitalisation is what follows digitisation. Digitalisation is the process of using digitised files, social resources and digital technologies to make fundamental changes to the operatoins of a business or a projectto ensure their success (Finsrud and Kristing, 2021). The ultimate stage of digital utilization is digital transformation. Digital transformation means going beyond digitalisation, it is the process of using digital technologies to modify an organisation's model to elevate the organisation and society (Aji et al., 2021). The phrase "Construction 4.0" was largely inspired by the 4th Industrial Revolution (Industry 4.0), it has achieved great success in the manufacturing sector and necessitates the amalgamation of the virtual and physical world by utilising the Internet of Things, virtualisation and simulation (Osunsanmi et al., 2018).

Construction 4.0 has two primary focuses, first, the transition from physical to digital, second, the transition from digital to physical. The aforementioned transitions assist with coordinating, designing and executing built environment infrastructures in a more efficient and effective manner. Construction 4.0 intends to fashion a digital construction site that utilises different methods to follow the progression of the life cycle of the project (Taher, 2021). One can view digital construction as a consolidated approach to state-of-the-art technologies which aim to make building safer and increase productivity. The construction industry has employed a variety of technological innovations such as 3D-printing, Document management, Virtual Reality (VR), Drones, Augmented Reality (AR), Computer Aided Design and Drafting (CADD) systems, Building Information Modeling (BIM), Artificial Intelligence (AI), and Collaboration platforms. Some of these technologies are not fully developed yet and they are quite expensive which is one of the reasons why they are not commonly used throughout most countries, including South Africa (Finsrud and Kristing, 2021). South African construction companies should utilise some of the above mentioned Construction 4.0 technologies so that they can accomplish digital transformation (Osunsanmi et al., 2018).

4 METHODOLOGY

This research endeavour seeks to explore the role of digitalisation and technology uptake in South Africa's construction industry. The inquiry followed the interpretivist paradigm which believes that reality is constructed socially and relies heavily on the various views and opinions that people have (Ngozwana, 2018). This study is an instrumental case study which means that Johannesburg played a supporting role to the phenomenon that is being studied (Crowe et al., 2011 and Lune and Berg, 2017). The research is qualitative in nature and was guided by qualitative methods. Some of the qualitative inquiries took place at various construction sites around Johannesburg while others took place telephonically and via email. The researchers sought out and relied heavily on the words of the interviewees in order to make inferences. Homogeneous sampling was used to select eight construction workers that were interviewed to gather data about their lived experiences. Homogeneous sampling ensured that the people who were interviewed would be the best people to assist with answering the research questions (Shaheen and Pradhan 2019). The eight construction industry specialists who were interviewed were found through Snowball sampling. The primary data collection tool was semi-structured interviews. They are flexible interviews that should yield a lot of

deep and rich information (Alshenqeeti, 2014). Journals, memos, company documents and other forms of documentation were used as secondary data sources. The data was analysed by using categorical aggregation and content analysis, both of which reduced, categorised, and clarified the data so as to yield answers to the research questions. Various methods such as member checking, peer debriefing and reflexive journaling were utilised to ensure that the research findings are valid and reliable. Lastly, the researchers ensured, to the best of their ability, that ethical procedures were adhered to at all times to ensure the success of the inquiry.

5 FINDINGS

The following findings are based on interviews with construction industry specialists and employees, as well as extensive literary works on the topic at hand. This section begins with a discussion about the stages and ways in which some of the construction industry's latest technological innovations are being used in South Africa. The advantages and disadvantages of the technology are explained followed by a proposal of how to implement and use these technologies in a sustainable manner.

5.1 The stages and ways of applying Construction 4.0 technologies in South Africa

Infrastructure development projects typically have four phases, namely, the Construction phase, Pre-design phase, Operation and maintenance, and Design/Engineering phase. Below we will briefly discuss how and when various Construction 4.0 technologies can be used after sampling some direct quotes from industry specialists and employees:

"To be honest, I think for FIRD we mostly focused on real time data"

"We use drones for photos on site to track construction progress or at the start of a project to document the site typography etc."

"We use BIM in all of our day to day activities and projects because it makes running the company much easier and keeps everyone happy"

"During designing, the land surveyors do contour surveys that we feed into our design programs, AutoCAD and Revit, where we can then design buildings and plan road layouts according to the contours and slopes because the programs allow for 3D rendering. You can then see what each stand will look like on site with the environment taken into account."

5.1.1 Drones

Drones are unmanned aerial vehicles that make it easier to access big, hard to reach, high-rise or complex areas. These devices are used to gather images, map information, and aerial photography data which is utilised for security control, monitoring the progress of construction sites (Figure 1), providing visual materials to employees and customers, building inspections and land surveying (Zaychenko et al., 2018 and Taher, 2021). Drones are mostly used during the construction phase (Ikuabe et al., 2020, March).

Fig. 1: Aerial Drone picture of Fleurhof Integrated Residential Settlement (FIRD) construction site (source: Calgro M3, 2015)

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5.1.2 Building Information Modeling

Building Information Modeling is a digital illustration of the physical and functional attributes of a site in two dissimilar features. Firstly, BIM can be used as a tool that assists with reducing information gaps by constructing and utilising a digital model. Secondly, BIM can be used to stockpile the model's data for the duration of its life cycle. This model is a combination of various processes, policies and technologies that assist with the management of project data and designs on a digital format throughout its life cycle (Ikuabe et al., 2020, March). Currently, BIM is thought to be a great contributor to the digitisation of the construction sector (Forcael et al., 2020). BIM has altered the way facility management, design and construction are handled (Zak and Macadam, 2017, September). Osunsanmi et al. (2018) stated that in order to fully enjoy the advantages of BIM, its use should be integrated with other innovations such as cloud computing which enable an easy flow of data inside the industry, as it has been predicted that it will transport data quickly to construction professionals by utilising cloud data storage.

5.1.3 Internet of Things

The Internet of Things is an instrument that supports the connection of various devices to the internet by utilising sensors and embedded software to converse, exchange and collect information (Forcael et al., 2020). Hindering construction companies from adopting IoT is the lack of data about its applicability in construction practices, as well as companies not having a vision for how IoT can be beneficial to the construction industry. In theory, the Internet of Things can be used in all phases of a construction project (Ikuabe et al., 2020, March).

5.1.4 Augmented Reality

AR is a publishing program and data platform that permits users to converse with people from various areas in real time, passively see material that has been viewed, and remain engaged and communicate with material that has been published (Taher, 2021). This innovation involves the method of integrating virtual components with real world objects with the goal of the user not being able to determine a change in the tangible world (Finsrud and Kristing, 2021). AR can be applied during repair and maintenance within the construction industry. The utilisation of a combination of AR and aerial 3D reconstruction can assist with better observation of a construction site (Ikuabe et al., 2020, March).

5.1.5 Virtual Reality

Virtual Reality is further up than Augmented Reality on the virtual spectrum. VR constructs an immersive virtual experience for the person that is wearing headsets that have 360° visions, this allows the user to interact with totally different environs (Taher, 2021). Virtual Reality can aid the decision-making and design processes through visualisation (Finsrud and Kristing, 2021). Within the construction industry, utilising VR training makes it easy to pinpoint dangerous areas, optimises procedures, and minimises the hazards people may come across (Forcael et al., 2020).

5.1.6 Robotics and Automation

Robotics and Automation are a simultaneous amalgamation of software, electrical, and mechanical engineering. The construction industry has forklifting robots, welding robots, bricklaying robots, drones, 3D printing robots, and demolition robots to name a few. The above mentioned robots can be used from project conception to project completion (Ikuabe et al., 2020, March).

5.1.7 3D Printing

Additive manufacturing which is also referred to as 3D printing is a procedure where a CAD model is used to manufacture a solid 3D structure (Ikuabe et al., 2020, March). Recently, such innovations have caught the attention of the Construction 4.0 sector, specifically with cement, illustrating the potential to replace employees with automated manufacturing, allowing efficient time management in addition to scalable and personalised construction manufacturing. The end product is largely influenced by printing duration between layers, speed, material behaviour, and printing quality (Forcael et al., 2020). 3D printing can be utilised during the construction, operation and maintenance, and design/engineering phases (Ikuabe et al., 2020, March).

5.1.8 Big data

The amalgamation of a variety of data, volume, and velocity is referred to as Big data. Variety alludes to the complex and diverse characteristics of sources and data categories. Volume represents the magnitude of the information that is gathered from networks, advanced technologies, and human interactions. Velocity exemplifies the rapid speed at which information is gathered when compared to traditional systems (Ikuabe et al., 2020, March). Big data could be converted into insights that are usable by utilising predictive analytics to assist businesses with actualising their objectives (Taher, 2021). Big data is mostly utilised in town planning and management, massive quantities of information are utilised to ascertain for example, the effect that social variables have on urban growth, and it can also be utilised to strengthen the standard of living of the residents of smart cities (Forcael et al., 2020).

5.1.9 Artificial Intelligence

Artificial Intelligence is a conceptualisation which refers to a computer that imitates human cognitive functions. It can also be used within the construction sector to differentiate various features of a construction site by using adaptive vision systems, they can also voice and recognise patterns to monitor the headway that employees have made (Forcael et al., 2020). An analysis of how it can predict multiple anomalies that are associated with services, construction and building architecture is being conducted (Taher, 2021). Artificial Intelligence is mostly used during the construction phase (Ikuabe et al., 2020, March).

5.1.10 Sensors

Sensors collect temperature, location, humidity and movement information (Sawhney et al., 2020). Throughout the operation and maintenance stage of construction projects, professionals can place sensors in strategic places within their construction sites so as to ease predictive maintenance, monitor deterioration and update their database (Ikuabe et al., 2020, March).

Advantages	**Explanation**	**References**
Productivity improvement	Construction 4.0 innovations facilitate the improvement of business productivity. Businesses should investigate how their employees utilise their time and execute a mechanism that improves the proficiency of systems. A software that schedules tasks can assist a business with fulfilling its obligations.	(Taher, 2021) (Osunsanmi et al., 2018)
Flexibility enhancements	During the past two decades, numerous technological advances have aided the improvement of communication amongst colleagues as they permit them to work remotely. These innovations have enhanced companies' capability to reply to customer/consumer enquiries faster and more efficiently.	(Taher, 2021) (Hořínková, 2021)
Business safety	Businesses should protect their data by utilising digital technologies and implementing methods that only key personnel would be able to navigate internally. Hackers will find it much harder to gain access to sensitive company data if encrypted passwords are used. As innovative technologies continue to be developed and launched, the transformation of companies will take place and they will enjoy the benefits.	(Taher, 2021) (Finsrud and Kristing, 2021)
Better customer services	Consumers are the bread and butter of all businesses, however, taking advantage of technological innovations will yield a bigger pay day. In order to boost profits and stand out from the rest, businesses should develop and provide around the clock customer care via social media, online chat support, and interactive sites.	(Taher, 2021) (Hořínková, 2021)
Lower cost of production	Implementation of Construction 4.0 technologies can reduce a project's total construction costs by 10-25%. Low requirements for construction site equipment and space, and rapid construction speed results in lower potential costs. The high speed of construction reduces the number of hours that employees work which in turn reduces the amount of money that is spent on their wages and accommodation.	(Hořínková, 2021) (Suliman Eissa Mohammed and Jamal Salem Alharthi, 2022)
Better time management	A cut of the project's duration is largely owed to moving a majority of the work to the inside of the plant, where productivity is not affected by weather conditions. Other positive contributors include work repeatability, digitisation and production automation. Various activities can be performed at the same time because of line production. For example the production of roofs, ceilings and walls is now possible at the same time.	(Hořínková, 2021) (Finsrud and Kristing, 2021)
Less negative impacts on the environment	Construction 4.0 produces less waste than traditional systems. The rapid assembly speed reduces the amount of time that surrounding areas have to tolerate the noise and air pollution that comes from the construction site.	(Hořínková, 2021) (Osunsanmi et al., 2018).
Potential provider of new opportunities	Digitalisation uses innovative digital technologies to better capitalise on current opportunities.	(Finsrud and Kristing, 2021)
Enhanced worker safety	The construction sector is responsible for over 20% of deadly accidents. Construction 4.0 technologies are safer because they reduce the amount of physical and outdoor labour that is needed, both of which are extremely dangerous.	(Osunsanmi et al., 2018). (Hořínková, 2021)

Table 1: Advantages of using Construction 4.0 technologies

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5.2 The advantages and disadvantages of using Construction 4.0 technologies in South Africa

There are various benefits and shortcomings of the utilisation of Construction 4.0 technologies, both of which are discussed below while considering the South African context.

Disadvantage	Explanation	References
Implementation cost	The deployment of Construction 4.0 technologies can be expensive when looking at ownership and operation. One should not forget that some of these technologies are still in the early development stages which means that they are still to evolve. It is also important to keep in mind that the costs of technical equipment training will accumulate. Time and resources will be spent during this training as it may require hiring a consultant to train the current employees.	(Hořínková, 2021) (Suliman Eissa Mohammed and Jamal Salem Alharthi, 2022)
Technology acceptance	There is concern about workers becoming redundant. Worried workers will hesitate to implement and utilise Construction 4.0 technologies. The adoption of emerging technologies could be affected by the above mentioned growing concern. Populism is one of the outcomes of this public concern and has resulted in a restriction of the employees' capability to respond to technological innovations.	(Taher, 2021) (Finsrud and Kristing, 2021)
High requirements	A qualified employee will be needed to use the new technologies so as to facilitate the transition and progression of Construction 4.0. Introducing Construction 4.0 technologies requires recruiting and preparing workers, in addition to acquiring integration expertise.	(Taher, 2021)
Lack of knowledge	Manufacturing and operations can be affected by the adoption of Construction 4.0 technologies. Complications with productivity, management structure, and work culture can be caused by the above. While there are plenty qualified workers within the sector that are open to implementing the emerging technologies, others may not share the same sentiments because they lack the expertise or desire to learn new techniques. Some construction companies may hesitate to incorporate these new innovations into their operations because of the above mentioned challenges.	(Taher, 2021) (Finsrud and Kristing, 2021)
Poor Long-Term Planning	The introduction of Construction 4.0 technology does not ensure the progressive improvement of a business, especially if it is not monitored closely. When designing a project, a risk analyses should be done and the long-term results should be considered. It is advisable to delegate a team that will monitor the project from conception until the end of the rollout period.	(Taher, 2021) (Hořínková, 2021)
Insufficient Support	If employees are not given a platform where they can voice their questions, opinions or concerns it could affect the business negatively. Employees should be prioritised and given timely assistance when they require it so that they do not hesitate to try to adopt and understand the new technology.	(Taher, 2021)

Table 2: Disadvantages of using Construction 4.0 technologies

5.3 A proposal of a viable scheme for the utilisation of Construction 4.0 technologies in a way that will ensure the sustainable development of South Africa

For the sake of the advancement of the conversion to Construction 4.0, South African construction companies should develop a strategic plan that details every step and decision to ensure transparency and comprehension by all. This plan should assist companies with determining their specific Construction 4.0 aims and developing methods for how to accomplish them. We propose that said plan should consist of five crucial strategies, namely, Strategic Management, IT Development, Smart Manufacturing, Smart Supply Chain Management, and Human Resource Management.

5.3.1 Strategic Management

Strategic management of a Construction 4.0 endevour is key for its success. It is important to select a team that will direct the introduction of Construction 4.0 and digital transition of the company, in addition to the merging of conventional technology with emerging technologies and systems. The team should formulate a transition plan, outline its steps, and describe the attributes of all the transformation stages. Lastly, the team should ensure that everyone understands the technical requirements, priorities, and internal and external performance drivers for every step of Construction 4.0 deployment plan (Taher, 2021).

5.3.2 IT development

The significance of ICT technology in assisting with the transition to Construction 4.0 is illustrated by innovations such as BIM, IoT and Cyber-Physical Systems (CPS) (Sawhney et al., 2020). Companies should start by conducting an exhaustive investigation of their IT infrastructure, which includes qualified personnel, IoT devices, applications, and hardware. What follows is an assessment of the level of IT development and determination of a business to adopt suitable IT strength for Construction 4.0 execution. The IT group has to determine which stages of the market require ICT intervention. If the current IT system is unsatisfactory then they will have to implement Construction 4.0 principles that are related to ICT. Lastly, the group should

ensure that the ICTs that have been adopted can integrate and align perfectly with the previous elements, in addition to ensuring that the entire mechanism is completely compatible (Taher, 2021).

5.3.3 Smart Manufacturing

The characteristics of Smart Manufacturing are connectivity, convergence, and transparency (smart construction site). Smart construction sites are making a change from a traditional manufacturing domain to one which is entirely interconnected, complex, and scalable, while depending on information gathering sources from various manufacturing processes (Sawhney et al., 2020). The application of Radio-Frequency Identification (RFID) and IoT devices is required in order to create smart communication in the manufacturing processes, as well as tactical mixing of personnel, procedures, equipment, databases, and materials to construct a smart construction site. Combining data mining processes with smart Enterprise Resource Planning (ERP) will assist with the invention of a digital mirror image that supplies the network's lifecycle with project details and some of its components for the entire production structure (Taher, 2021).

5.3.4 Smart Supply Chain Management

Supply chain relations have been largely affected by the Construction 4.0 transition as a result of the improvement of data creation tools and the immense digitalisation of operations. Partners should align and integrate their procedure's digital twins in a way that will enable the construction of a smart digital supply chain. This application focuses mostly on Information and Communications Technology organisation in the supply chain which should result in real time data and accessing of data. Utilising blockchain innovations will assist the supply chain with maintaining confidentiality and consistency of data. This is an area of concern within the transition as it safeguards various stakeholders' intellectual assets (Suliman Eissa Mohammed and Jamal Salem Alharthi, 2022). Full integration of manufacturing and managerial skills, materials, finances, operations, and data flow would facilitate the creation of a smart value chain which performs a necessary function in digital transformation. Smart production and Smart value chain convergence permits the cumulation of real time data from multiple operations processes, partners, and customers which results in an increase in supply chain value (Taher, 2021).

5.3.5 Human Resource Management

The final step of the plan to implement Construction 4.0 is the creation of a human resource plan. One of the most important things to consider when planning a successful digital transformation is hiring proficient employees. Construction 4.0 can create a mutual connection among the virtual and real worlds by utilising ICT innovations such as cybersecurity, BIM, cloud networking, modelling systems, IoT, RFID, and CPS. Only employees that are trained in a related field and have exceptional technical expertise can make such a shared connection happen (Osunsanmi et al., 2018). In order to meet Construction 4.0 transition criteria, businesses should carry out a thorough assessment of their workers' technological skills and identify their current competence gap. Current employees possess a big advantage with a state-of-the-art supply chain, the best thing to do is train and prepare them to execute the principles and innovations that are proposed by Construction 4.0. Developers should aspire to hire multi-skilled employees that are keen to learn about the latest ideas and techniques (Taher, 2021).

6 CONCLUSIONS AND RECOMMENDATIONS

Remiss of the value of the construction industry to South Africa, developments inside the industry are characterised by conventional methods and small-scale implementation of ICT that yields the construction of substandard infrastructures, thus, affecting the general conduct of the construction industry. The paper acknowledges that Construction 4.0 will be guided by a call for the creation of a smart construction site, in adddition to adopting simulation softwares and virtualisation for construction processes. This endevour has come to the conclusion that digitalisation cannot be taken advantage of fully in South Africa's construction industry without key transformations and adaptations of procurement arrangements, business models and improving the construction industry. The above mentioned advances are imperative to realise the sustainable development of South Africa through the implementation of Construction 4.0. The researchers determined that the advantages of Construction 4.0 can, in theory, remedy some of the challenges that are faced by the construction sector in South Africa, as they far outweigh the disadvantages. Nevertheless, research within this area is still limited and multiple problems with implementation remain. Specifically, there is a lack of

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case studies that are centred around or related to the topic at hand. This inquiry recommends the endorsement of Construction 4.0 by construction stakeholders to enhance the general performance of South Africa's construction sector and create awareness about the endevour. In addition, an investment should be made in research which focuses on the implementation of innovative ideas and technologies that can be utilised by the South African construction industry. Lastly, a proactive thinking approach should be adopted by construction sector professionals when tackling their projects.

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