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Influential Factors Affecting the Diffusion of Building Information Modeling in South African Construction Projects

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Abstract
Sustainability has become the focus of many clients in construction projects, but conventional construction stakeholders' services do not promote sustainability throughout the construction process. Conversely, Building Information Modeling (BIM) has been identified as a tool that construction stakeholders can use to enhance the sustainability of construction projects. However, the majority of South African construction projects still do not utilize BIM. Therefore, this study aims to understand the influential factors affecting the low adoption of BIM in South African construction projects. To achieve the aim of the study, the research study implemented the qualitative research approach. The data collected from semi-structured interviews with several South African BIM experts produced invaluable qualitative data. The collected data was thematically analyzed to extract key findings and themes concerning the key influential factor and their sub-factors on BIM adoption in construction projects. Four identified influential factors and their sub-factors affecting the diffusion of BIM emerged deriving from the findings discussed in the research study. Based on these findings, it was proven that BIM could improve the sustainability of construction projects. Numerous conclusions and recommendations were proposed in this research study targeted at increasing the adoption of BIM intended to enhance the sustainability of construction projects.

Keywords
BIM, Construction projects, Influential factors, Level of adoption, South Africa.

1. Introduction

Sustainable construction has come under the spotlight in the industry in recent years resulting from an awareness of the need to address the life cycle costing of the building (Moghayedi *et al*., 2021). Furthermore, sustainable construction plays a significant role in impacting the construction project's social, environmental, and economic factors by striking a balance between these factors during the construction project's life cycle (Yilmaz and Bakış, 2015). Traditionally construction projects' focus is on time, cost, and quality. However, in recent years, there is an awareness of the life cycle impact of the building, particularly on the social, environmental, and economic sustainability factors, and this propelled sustainable construction to become a crucial concept in evaluating the overall success of the project (Kamali and Hewage, 2017). Furthermore, the sustainability of the construction project can be positively impacted through the adoption of BIM throughout the various stages of the project by all the construction stakeholders to ensure projects remain within project specifications (Ullah *et al.*, 2019).

However, construction stakeholders in developing countries such as South Africa remain stuck in traditional practices (Moghayedi *et al.*, 2022). They are hesitant to adopt BIM due to their lack of understanding of the potential uses and benefits (Gilchrist *et al*., 2021). Construction stakeholders need to realize the benefits of BIM instead of opposing this technology and rather should adopt and implement it.

Awwad et al., (2020) state that the developed countries such as the UK government strategies for more sustainable construction through the following key factors: a design for minimum waste, applying lean construction principles, minimizing energy in construction and use, pollution reduction, preservation and enhancement of

biodiversity, conservation of water resources, respect for people and local environment, setting targets to benchmark performance and that these factors need to be incorporated throughout the lifecycle design of the construction project. Specifically, regarding the pre-construction stages of the construction process, the primary strategies implemented to contribute to the sustainability of the construction project are processes such as site selection, flexible and durable design, and selecting sustainable materials (Yılmaz and Bakış, 2015). Most of a buildings' negative impacts on sustainability are undertaken in the early design stages of construction. Past research has recognized the importance of the early design stages in reducing buildings sustainability (Carvalho *et al*., 2020).

Construction projects have become more complex, and the complexities surrounding big construction projects result from thousands of documents and drawings being processed and used manually (Gilchrist *et al*., 2021). Two-dimensional information management can result in miscommunication amongst the design and construction teams and often times are inadequate for complex projects. Miscommunication can result in mistakes made during construction such as poor design, outdated drawings used, delays, cost overruns, poor quality and design clashes with BIM existing as an innovative technology that can improve the inefficiencies of conventional construction information management (Carvalho *et al*., 2020).

The positive impact that BIM can have on the sustainability of construction projects and the construction industry, in general, is essential (Awwad *et al*., 2020). BIM can shift the construction industry from the 'conventional' paper-based approach to a cloud-based collaborative 3D model process and allows sustainability to be measured throughout a project's life cycle.

Construction stakeholders prefer conventional practices rather than proactive in approaching BIM (Carvalho *et al.*, 2020). There is believed to be a lack of understanding of the potential uses and, more importantly, benefits of BIM (Gilchrist *et al*., 2021). The construction industry remains one of the slowest adopters to new innovative technologies, with the South African construction industry being no different.

BIM has become a central focus amongst construction stakeholders due to the improvement in productivity and efficiency it offers (Gilchrist *et al*., 2021). However, the barriers to adoption are believed to be poor connectivity, high software costs, lack of international certification and lack of understanding of the uses and benefits of BIM in South Africa (Gilchrist *et al*., 2021). These reasons have negatively affected BIM uptake amongst construction stakeholders in South Africa.

Sustainability has become at the forefront of many industries worldwide, and previous research shows the importance of sustainability, especially in the construction industry (Carvalho *et al*., 2020). BIM gives construction stakeholders the ability to become drivers of economic sustainability in the construction industry.

Despite the benefits and potential of using BIM on construction projects to enhance the sustainability of the projects and able construction stakeholders the ability to become drivers of economic sustainability in the construction industry, South African construction professionals prefer using their traditional methods and practices.

Therefore, there is a need to identify the key influential factors associated with BIM diffusion in South African Construction Projects. As its central aim, this study seeks to develop this knowledge base through the establishment of the BIM adoption conceptual framework for the South African construction industry.

2. Research method

Since the influential factors affecting the diffusion of BIM in South African construction projects are still a less explored area, it requires utilizing qualitative techniques to collect data from the experts to investigate this little-understood phenomenon as proposed by Creswell and Creswell (2017).

Deploying semi-structured interviews in the present study aimed to provide a basis for conceptualizing the key influential factors in the adoption of BIM in South African construction projects.

The number of interviewees was considered to be between three and 16, as a reasonable preliminary estimation for defining the sample size (Bazeley, 2013). Thus, an initial list of 10 South African BIM experts was identified. As a result, interviews were reached saturation point after conducting interviews with five interviewees whose profiles are detailed in Table 1

Table. 34. Interviewees' profiles

Code	Professions	Experience in BIM	Organization	Project size
1	Quantity surveyor	5 years	Engineering consulting	Large
2	Construction manager	7 years	Developing	Large

3	Architect	3 years	Local government	Large
4	Quantity surveyor	4 years	Quantity surveying consulting	Large
5	Structural engineer	8 years	Engineering consulting	Large

For this research, an inductive approach has been adopted. The structure of the study was developed through the data that was collected. Following this, a thematic analysis of the data collected was employed as this is a commonly used inductive approach to analyzing data. Common themes (influential factors) and sub-themes were identified in the interview transcripts using NVivo, and these themes were used for developing the conceptual framework.

3. Results

Examining the data extracted from the transcribed interviews, the following common themes (influential factors) and sub-themes emerged throughout:

3. 1 Barriers and challenges concerning BIM adoption

Barriers and challenges relating to BIM adoption is influential factor that emerged throughout the data collection gathered through the research. It is concerned with the issues surrounding the broader adoption of BIM technology in the construction industry. The five sub-factors of that form from the barriers and challenges theme discuss below.

1.1.1 The disconnect between design and costing of 3D models

When applying cost to BIM models, Participants1 stated that a disconnect exists between how modeling software is used in building design contrasted with how costs are applied. Participant 1 noted that the way QSs produce cost reports by following the South African Standard System of measuring differs drastically compared to how architects design buildings.

> *"There is a disconnect between how the modeling software is used and model the information and how they translate to cost".*

This is further corroborated by Participant 3, who suggests that designers need to collaborate when designing the BIM model. This leads to a more comprehensive design and aid in all the components being coded correctly.

Participant 5 further elaborates on the importance of having comprehensive and correct information in the model to allow cost reports to be produced more accurately. Finally, participant 5 explains the need for all the design consultants to work together to achieve more accuracy within the 3D model.

1.1.2 Lack of awareness of BIM capabilities

According to Participant 1, there are varying levels of BIM adoption in the South African construction industry. Thus, affecting the level of awareness by designers concerning the capabilities of BIM. If these capabilities are known, BIM would be used to its full potential.

Participant 5 emphasized the need for the use of BIM to extend past the detailed design stage of construction.

> *"But the problem in South Africa and most countries where it hasn't taken off is that everything stops at this stage in the detailed design. So, at this stage, we complete our designs and prepare tender documentation and print on hard copy and issue to the contractor at the beginning of the construction period, so that is where the model stops and doesn't go any further than that".*

Participant 3 emphasized that the main benefit of using BIM for the lifecycle of a building is not applied currently enough in the South African construction industry. Furthermore, Participant 3 alludes to the fact that many contractors are unaware of BIM completely, which acts as a barrier to its adoption.

1.1.3 Lack of training and experience using BIM

The learning curve associated with measuring from 3D models was steep, according to Participant 3.

> *"Due to time pressure always being a factor, they decided to revert to measuring from 2D drawings as they lacked the prior training and experience."*

Participant 1 further details the current lack of training and experience in the South African construction industry concerning BIM. Furthermore, they state a level of adoption among the larger design firms, but the level of training and experience varies drastically depending on the individual. Many designers use 3D modeling software to draw in a 2D space.

Many consultants simply do not have the necessary time to learn how to use 3D modeling software adequately.

> *"It is a specialist thing and requires a training course about it. I think a lot of people who have worked for 3D measuring software companies have been trained in BIM to sell a specific product."*

1.1.4 Poor quality of BIM models

Participant 2 believes that even in developed countries though the architects that work in the country are advanced and well trained in BIM, the quality of their 3D models is not up to the desired quality. When busy with cost reports, one has to check the 2D drawings to ensure that these align, so no major mistakes are made. The poor quality of these 3D models causes BIM to be inefficient.

> *"In the UAE, we are more advanced in BIM modeling as we use prestigious architects that are trained fully in the system using updated technology but still the quality is still poor. We still have to go back and check specifications to the drawings".*

Participant 4 states that the design consultants do not have enough to code and design BIM models due to time pressures properly. Furthermore, Participant 4 believes that BIM was developed in a perfect world where designers can produce BIM models properly. However, an ideal BIM is yet to be seen by Participant 2, and they believe that it will be a long time until this is achieved more consistently.

1.1.5 Fragmented industry

Collaboration is a difficult task to achieve when working on BIM models, according to Participant 1. The industry is very fragmented due to the current economic climate.

> *"There is a lot of resistance in the industry especially from directors in architecture and quantity surveying firms to adopt new technologies".*

Due to the high cost of adopting BIM, many construction companies and consulting firms do not believe the cost of adoption is worth the investment, according to Participant 3. This has led to a very fragmented industry where only some companies have the capabilities of using BIM in construction projects.

3.2 Benefits of adopting BIM in construction projects

The benefit of adopting BIM in construction projects is another influential factor that emerged throughout the data analysis. It is concerned with the advantages of implementing BIM in construction projects. Five sub-factors of benefits of adoption BIM emergent theme are discussed below.

3.2.1 3D Visualization

Participant 1 emphasized the importance of visualizing the building. This assists the architects and engineers in fully understanding and coordinating their services and equipment effectively to go into the building to limit the number of runs. Similarly, Participant 4 highlighted the most significant advantage of BIM is the 3D visualization, where you can fully understand the more complicated designs when it comes to Mechanical, Electrical, Plumbing services.

> *"Currently, the one advantage would be when you review the drawings so 3D models you can look at that building upside down left and right. You can see every angle of that building".*

Participant 5 noted that the 3D visualization that comes with BIM assists the clients who cannot understand the 2D drawings.

3.2.2 Clash detection

Participant 1 explained that the 3D model had been used for coordinating services in the design, reducing the number of clashes that occur on-site. Consequently, this reduces the cost and number of delays that occur during the project.

> *"Project stakeholders are being more and more used as a coordination tool to coordinate their general arrangements designs with the coordination of the services to minimize the number of clashes that we do experience on-site because that is a very costly and time nightmare for contractors".*

Participant 4 further explained the consequence of reducing the number of clashes on the project. The designs of the MEP engineers are complex, and with the 3D model, there will be a better understanding of the system, which can alleviate the wastage that comes from the project. This can be attributed to not only saving the time and cost of a project but also the effect of not extending the project timeline. If extended, staff will need to come to the site, cars, plants, equipment, use of facilities, all that pollution and waste can be indirectly alleviated through BIM.

3.2.3 Less redundant

Participant 1 emphasized that it may be less measuring being done, but the time now will be spent checking the quantities of the model and making sure that the information is accurate.

Participant 2 highlighted how the company had a team that would conduct measurements for the estimates off 2D drawings. However, most of the measurement team was retrenched due to the COVID-19 pandemic and the economy. Now, they extract quantities off the BIM model, and it is much faster in delivering estimates and cost reports to clients.

> "*That measurement process took long because they would measure off normal 2D plans, so they would take like two weeks to measure. So now we are measuring ourselves, extracting off the BIM models which is much quicker".*

3.2.4 Manage information flow

Participant 1 stated that there needs to be absolute synergy and collaboration for BIM to be successful. Therefore, international markets are set up as turnkey solutions where there is no separation between the professionals.

> *"It does necessarily need to be a turnkey situation. There needs to be better communication between the designer and construction teams."*

Participant 5 stated that with the BIM, any changes that the architects make automatically update their design protocols, and as such, they do not have to start from the beginning from the first principal design, so with BIM it redesigns everything with the updated information, and they just need to check if it is done correctly and resubmitting.

3.2.5 Minimize time and cost

Participant 1 believes there is a benefit for BIM in ensuring that the ongoing maintenance and operational cost of the building are looked after and evaluated.

Participant 3 explained how BIM could be used as a checking tool if there is a dispute with the contractor of the rate of an item and the bill of quantities database that can search for that specific item; no contractor can argue with that amount of data the rate is incorrect.

> *"With BIM, there is much less chance of making errors because you are not taking information from one platform, so there is no room for error".*

3. 3 Drivers of BIM Adoption

Drivers of BIM adoption was a theme that emerged throughout the data collection gathered through the research. It is concerned with the issues surrounding the wider adoption of BIM technology in the construction industry. The drivers of BIM adoption contain three sub-themes.

3.3.1 Owner/Client involvement

Participant 5 believed that more should be done to drive BIM adoption in South Africa in government projects. Participant 5 believes that BIM adoption throughout all new government projects in the UK will allow construction projects in the UK to attain 5D and 6D BIM in the next couple of years. The government played a key role in the sudden surge of BIM adoption in the private sector. Additionally, Participant 5 states that private clients must also drive BIM adoption in construction projects. If clients and government are aware of the benefits of construction and operation of buildings using BIM, they will require the professional team to be adequately capable of using BIM.

Participant 2 outlines a negative associated with clients driving the use of BIM. Participant 2 states that the professional fees of the QS can be linked to the time taken to produce cost reports, especially in the pre-contract phase of construction.

> *"So, when we are producing the bill with 2D drawings in UAE, we take longer and produce more fees, but now they are saying we can give you less fees when you use the BIM model because instead of taking two weeks to measure, we now take two days and useless people, so we get less fees as well".*

Therefore, BIM can make reports more efficient, albeit with the accuracy of BIM models still being unsatisfactory, according to Participant 2.

3.3.2 Utilizing by Contractor

Participant 5 expressed the need for contractors to give the as-built BIM model to the client after they have completed the construction of a new building. Giving the client the most accurate up to date model due to design and construction differences.

> *"A lot of contractors in the UAE have their own BIM specialists, and they will ask for the BIM drawings and measure it out to make sure it is correct. They will do quantity checks as well."*

Participant 4 shares the same opinion as Participant 5 for the need for contractors to be BIM capable. If the contractors have BIM specialists in their companies, this gives them the ability to provide clients with the most accurate 3D models once the building is completed. In addition, it allows the client to utilize the capabilities of BIM better.

3.3.3 Utilizing by consultants

Participant 1 explains that in their own experience, the consultants who possess the ability to drive the use of BIM for design on construction projects are either architects or engineers. Therefore, they possess the necessary training and experience in using BIM software for design. Currently, these consultants are primarily being used as coordination to lessen the probability of clashes in design between architects and engineers.

> Participant 1: *"…depends really on the driving consultant, which is typically the architect in many cases, but we do find in certain instances the engineers are somewhat the driving and lead designers".*

Participant 4 and Participant 2 also state that the driving consultants of BIM on construction projects are mainly the architects and engineers in the UAE.

3.4 Guidelines for BIM Models

Guidelines for BIM models was a theme that emerged throughout the data collection gathered through the research. It is concerned with the level of quality the BIM model should have to achieve full 4/5D implementation. The five sub-themes of guidelines for BIM are discussed below.

3.4.1 Standard Model for BIM

Participant 2 explains that they have a BIM team with a system in place and documents that the architect needs to follow when they produce the BIM models. Participant 2 further notes that even the clients have certain guidelines, the BIM model needs to meet particular standards.

Participant 3 believes that it is critical for the future of BIM. The designers and QSs need to collaborate because they think differently. Every component that the designers draw needs to be coded and structured in a certain way.

Participant 5 states that they follow the new ISO standard for their model, where it focuses on not only the 3D design but also the data within the model.

> *"We follow the new ISO standard. It focuses not only on the 3D drawing but also the data model, so we ensure that data is in this 3D model.".*

3.4.2 Creation of an as-built model

Participant 5 emphasized the importance of creating an as-built model that does not stop at the design stage but instead gets developed through the other stages and contains data that will make the model useful for the client for the operations and facility management of the building lifecycle.

> *"From construction to the as-built is what we are currently doing now, and this is what makes BIM work is to take it through the construction stage have a proper as-built model with all the data required to take it to the next stages".*

3.4.3 Designing to a standard system

Participant 1 states the importance of the standard system, and to fully have the BIM model automatically produce an estimate, it needs to be designed according to the standard method of measurements.

> *"It separates materials obviously because certain materials are costed differently and if it exceeds certain parameters, the cost of that material increases but it also sets the labor component".*

3.4.4 Trusting accuracy of BIM models

Participant 1 expressed the fallacy around extracting quantities from the model, reducing time in measuring as the model can be inaccurate and the time spent measuring will now be spent checking the model's accuracy. Participant 1 states that as a professional, you need to have confidence in the quantities, and if you blindly rely on the model for the quantities, you are not 100% certain of the quantities.

Participant 4 also emphasized the importance of trusting the BIM model and the impact of doubting the information from the architect.

> *"But once you check and find that 1st error in a BIM model, you will start to doubt the information that you received from the designer."*

The emerging influential factors and sub-factors extracted from the data analysis are conceptualized in Figure 1.

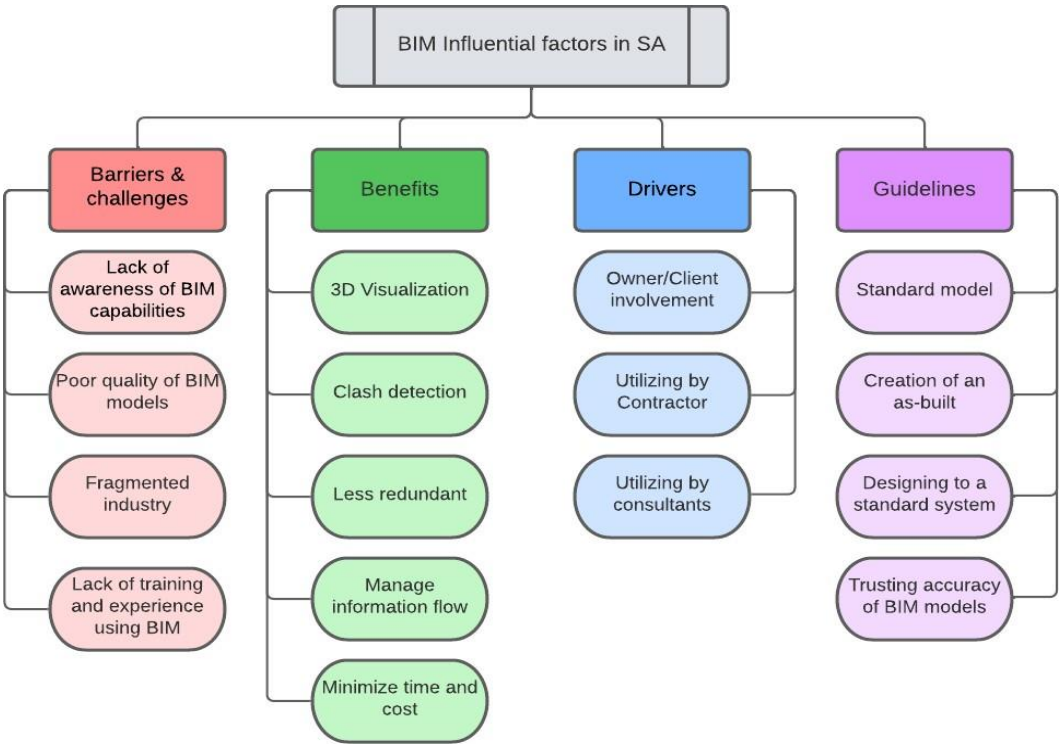

Fig. 35. A figure caption is always placed below the illustration. Short captions are centered, while long ones are justified.

4. Discussion

The research findings show several barriers and challenges in adopting BIM in South Africa.

These findings support the research findings of Akintola *et al.* (2017), who state that industry fragmentation hinders BIM adoption in the construction industry. Therefore, poor collaboration from the project team hinders the ability of the BIM model to be produced accurately.

In addition, Oraee *et al.* (2019) and Akintola *et al.* (2017) assert that a lack of support from the government regarding policies, practices, knowledge, procedures, and drivers concerning BIM acts as a barrier to BIM adoption. Secondly, Oraee *et al*., (2019) note the high costs of implementing BIM technology as significant barriers to adoption. Awwad *et al*., (2020), states that a lack of understanding/training of professionals acts as a barrier to the adoption of BIM in the construction industry as the performance of BIM is not optimized due to the learning curve it requires.

Based on the findings, it is apparent that there are many benefits to utilizing BIM in construction projects. The results suggest that BIM greatly assists with 3D visualization, clash detection, managing information flow and minimizing time and cost. This aligns with the research findings of Ullah *et al.* (2019), Oraee *et al.* (2019), Gilchrist *et al*., (2021), who believe that the improved visualization and modeling capabilities enhance the productivity and coordination of the construction project. The collaboration of the professional team and the coordination of services are further supported by Oraee *et al.* (2019), who notes that BIM reduces errors and clashes, which prevents unnecessary reworks which correlate with the findings which indicate the understanding and coordination of the engineering services reduce the number of clashes before designs go to the site.

The findings relating to the use of BIM to extract quantities are further corroborated with Gilchrist *et al*., (2021), who expresses the efficiency of extracting quantities with BIM to produce budgets and estimates.

The key individuals/organizations which drive the adoption of BIM are vital to the further adoption in the wider construction industry. The findings displayed those clients, i.e., government or private, are the primary drivers of BIM adoption in the construction industry. Additionally, the role that contractors and consultants play in the adoption of BIM on construction projects is also key to further adoption in the industry.

These research findings are supported by the findings presented by Akintola *et al.* (2017). They state that a lack of guidance and drivers from government authorities hinders the construction industry in adopting a standard for BIM models. Implementing policies and standards for BIM models, such as BIM utilising mandatory in public and infrastructure construction projects, will drive BIM adoption throughout the country.

The findings relating to the guidelines for the BIM model suggest that the model needs to follow a standard and contain relevant data in the BIM model. This corresponds to the research done by Akintola *et al.* (2017), who highlighted the importance of government agencies to drive BIM implementation and develop guidelines for construction projects. Akintola *et al.* (2017) further state that the construction industry stakeholders in South Africa need to agree on a standard to adopt and provide guidelines. This is reflected in the findings, which indicate that the participants follow the BIM ISO standard for their BIM model, which enforces a system that the designers follow when producing the BIM models. This finding corresponds with Kuzminykh *et al.* (2022), who states that the quantities extracted from the BIM model need a standardized coding system to be accurate and consistent.

In addition, the findings indicate that the accuracy of the BIM model is important to achieve full integration of 4 and 5D BIM. However, the participants still find themselves doing checks and getting huge errors flagged. The importance of the accuracy of the model is further supported by Kuzminykh *et al.* (2022), who states that the data in the model could contain duplicates and errors if not classified in a relevant coding system; this results in the inaccuracy of the quantities and affects the integrity of the estimates.

5. Conclusions

The adoption rate of BIM in South African construction projects is low, and there are a few South African construction companies are apprehensive about implementing BIM. Therefore, understanding the key influential factors on the diffusion of BIM in South African construction projects is of paramount importance to adopters and policymakers at both construction companies and the industry level.

In conclusion, the results provide strong evidence that BIM impacts the sustainability of construction projects through providing improved visualization of the building for construction stakeholders, clients, and contractors, thus lowering the possibilities for clashes in the design and construction, better management of the flow of construction and design information and minimizing the time and cost of the construction project.

From the conclusion that BIM significantly impacts the efficacy and accuracy of construction projects, it is recommended that South African built environment professionals implement BIM in their construction projects as enhancing the project's sustainability is beneficial to the client and the construction industry.

It can also be inferred from the study's findings that there is a lack of understanding from construction stakeholders regarding the full capabilities of BIM. As a result, the designed model has insufficient data or no standard in place so that it can be effectively used for optimum adoption of BIM. Also, it was discovered that there should be more guidance and influence from South African government authorities to improve the adoption of BIM by enacting a standard/guideline for the BIM model. This improves the quality of the BIM and enhances the accuracy of full BIM implementation.

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