THE NEXUS BETWEEN BUILDING INFORMATION MODELLING IMPLEMENTATION STRATEGIES, ADOPTION, AND LEVELS OF CONSTRUCTION SUPPLY CHAIN INTEGRATION IN SOUTH AFRICA

By

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ABSTRACT

The adoption of Building Information Modelling (BIM) on construction projects is not widespread yet, because there is a growing albeit slow uptake. There is no strategically structured BIM adoption guide available on construction projects for ensuring integration and collaboration among the Building Information Modelling- Supply Chain Members (BIM-SCM). Scholars adduce the lack of adoption of BIM on construction projects to the use of ineffective BIM implementation strategies. Therefore, this research investigated BIM adoption and the current dominant BIM implementation strategies used in the South African construction industry. It also examined whether BIM implementation strategies and BIM adoption on construction projects impact on the occurrence of integration and collaboration among the BIM-SCM in the South African construction industry.

Using modified Implementation Process Theory, the research collected primary data using a mixed-methods research approach that involved the collection of both qualitative and quantitative data from 872 respondents randomly selected from the 1,871 BIM-based construction projects' direct participants who indicated their willingness and availability to participate in the research from the cidb databse of construction professionals in South Africa. The qualitative data collected with respect to barriers to BIM adoption and dominant BIM implementation strategies were analysed using thematic analysis. The quantitative data collected with respect to BIM adoption, barriers to BIM adoption, integration and collaboration, and BIM implementation strategies were analysed using Mean Item Score (MIS), Confirmatory Factor Analysis (CFA), and Structural Equation Modelling (SEM).The SEM method used was the Maximum Likelihood Estimation. Before modelling process, CFA was used to confirm the validity and reliability of the quantitative data using the Factor Loading, Eigenvalue, correlation coefficient, Kaiser-Meyer-Olkin (KMO) value, Bartlett's test results, and Average Variance Explained (AVE).

It emerged that the possibility of getting high-value clients, quest for a competitive edge, need for technological sophistication, need to be socially acceptable to the clients, incorporation of BIM adoption into the vision of the organisations, and development of BIM capabilities as new values in their organisations are the dominant BIM implementation strategies used in the South African construction industry. The findings also revealed that the dominant BIM implementation strategies are private driven and are not bringing about an adequate reduction in the BIM adoption barriers. Investigation of the evidence of the application of BIM tools and processes with respect to the adoption of BIM on construction projects showed that fewer building information models were developed for projects, BIM performance assessment was not intensive, emphasis was not placed on the level of objects' clarity of building information models, BIM skills and competencies were insufficient, and BIM management was dis-organised.

The parameter estimates from the SEM analysis of the interactions between the BIM implementation stages indicated that the success of the BIM implementation process in South Africa depends on a positive interplay between the interacting implementation stages. The parameter estimates from the SEM analysis of the interaction between the BIM implementation stages also revealed that BIM implementation strategies control the impacts of a reduction in BIM adoption barriers on the extent of BIM adoption. However, the findings revealed that the BIM implementation strategies currently in use did not possess the required forces and intensity to strengthen the positive interplay between the interacting BIM implementation stages.

The study concluded that the essential BIM implementation strategies are not in use in South Africa, while the BIM implementation strategies currently in use are not appropriately and effectively employed. However, there is evidence of elementary BIM adoption on projects and low occurrence of integration and collaboration among the BIM-SCM in South Africa. The lack of adequate skills and experience of BIM management and the inadequate understanding of what BIM adoption on projects entails mean that working policies and legislation on BIM adoption are required to drive a successful BIM implementation process. This research provides new insights on the structures and stages of the BIM implementation process and postulations that will aid the comprehension of the interconnections between BIM implementation strategies and BIM adoption on construction projects in South Africa. More importantly, this research has extended the existing theories on BIM adoption and the interactions between the levels of BIM adoption on construction projects and collaboration among the BIM-SCM.

Keywords: BIM; BIM adoption; BIM implementation; Integration and Collaboration; BIM adoption barriers; South Africa

DECLARATION STATEMENTS

I declare that all the information contained in this thesis has been collected and presented in accordance with ethical rules and academic conducts of the University of Cape Town. I hereby declare that this thesis signifies my own work which has never been submitted either in parts or whole for the award of any degree, diploma or any other qualifications, except where due acknowledgement has been made in the thesis.

OLUGBOYEGA Oluseye

Signed: Signed by candidate

DEDICATION

This work is dedicated to the Almighty God and my mother, Mrs Florence Gboyega-Kehinde.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Research context

This research investigates the Building Information Modelling (BIM) implementation strategies that bring about a reduction in barriers to BIM adoption towards ensuring better integration and collaboration among the BIM supply chain members (BIM-SCM) in South Africa. To that end, the Implementation Process Theory, modified with postulations on the requirements and challenges of BIM adoption and implementation, was used in framing this research.

BIM is an innovation that provides technology for BIM-SCM to perform their roles, provides processes for performing those roles, and serves as management systems for integrating, coordinating, and controlling building design, construction, and operation activities (Papadonikolaki and Wamelink, 2017; Fitriawijaya and Hsin-Hsuan, 2019). BIM supply chain describes the supply chain stakeholders (such as client, designers, general contractor, subcontractor, supplier, consultant, estimators, suppliers, fabricators, facilities managers, surveyors, and project managers) and the construction business network (from the demands by the client, conceptual design and construction to maintenance, replacement and eventual decommissioning of the building) for transferring products, services, and information for the execution of BIM-based construction projects (Ahuja et al., 2020; Zhang et al., 2020). In BIM supply chain, construction professionals and subcontractors make use of tools and technologies to develop project information, while the project or BIM managers make use of construction management systems to control and coordinate the activities undertaken by BIM supply chain stakeholders and the project information (Durai and Sentanilselvan, 2016; Bossard, 2016; Mostafa et al., 2020; Khanzadi et al., 2020).

The following benefits have been attributed to BIM implementation in the construction industry: elimination of design errors, cost reduction, improved quality of information, integration of project systems and information, improved effectiveness of work processes, and improved productivity and effectiveness of the construction industry (Tezel et al., 2020; Al-Ashmori et al., 2020; Yusuf et al., 2016; Getuli et al., 2016; Liu et al., 2017; Wang et al., 2017). More important is the usefulness of BIM as a construction management system for ensuring integration and collaboration among the BIM-SCM (Li et al., 2019; Khalfan et al., 2015; Yussuf et al., 2016). There are various systems of applying BIM on construction projects depending on the level of details and development of project information, the intensity of the BIM process, and the usage of BIM tools, technologies, and capacity (Cao et al., 2015; Zandieh et al., 2016). These systems have been categorised as 3D, 4D, 5D, and 6D ~ nD BIM (Kaewunruen et al., 2020; Lee et al., 2020; Koutamanis, 2020; Bolshakova et al., 2020; Acampa et al., 2020).

BIM implementation refers to the process of ensuring the adoption of BIM tools, technologies, platforms, processes, and principles on construction projects (Shirowzhan et al., 2020; Silva et al., 2016; Wernerová et al., 2020). BIM implementation provides the opportunity for the enhancement of the global competitiveness of indigenous construction firms and professionals in developing countries. According to Junior et al. (2020) and Yussuf et al. (2016), BIM implementation determines the quality, efficiency, and competitiveness of a construction industry, which makes it the best way to ensure quality works, workers efficiencies, and competitiveness of firms and professionals. Besides, the potentials of BIM in addressing the needs of the construction industry has made BIM the international standard of project design, construction and management systems; and its implementation in the construction industry can be used to build the quality and competitiveness of architectural, engineering and construction practices (Mostafa et al., 2020; Guzzetti et al., 2020; Zhang et al., 2020). However, the process of implementation begins with the identification of barriers to BIM adoption (Siebelink et al., 2020; Zhou et al., 2019; Mirarchi et al., 2020).

BIM adoption is an act undertaken by construction organisations or professionals to take up or follow the provisions and guidelines of BIM as given in BIM implementation requirements (Uhm et al., 2017; Brunet et al., 2019; Qin et al., 2020; Troiani et al., 2020). In other words, BIM adoption refers to the formal acceptance of BIM by construction organisations and professionals as a working system (technology, process, and management) in the construction industry (Qin et al., 2020). According to Lu et al. (2018) and Liao et al. (2019), BIM implementation initiative is a national or industry issue, therefore it depicts a formal acceptance of BIM by the industry leaders and policymakers to be globally relevant and competitive. BIM adoption, on the other hand, depicts initiatives at the level of organisations or projects based on the expectations of the organisations or the clients and within the provisions of BIM implementation initiative. This shows that BIM implementation is a product of political will or legislation and it requires strategies, plans, decisions, regulations, and guidelines to bring it into effect, while BIM adoption is a product of requirements by clients or organisational vision. Without BIM implementation requirements, BIM adoption is not legally binding on organisations or professionals, except it was demanded by clients. Even with BIM implementation, BIM adoption is still not legally binding on organisations or professionals if the clients (public or private) do not mandate it.

Barriers to BIM adoption are the obstacles or factors that frustrate the BIM implementation process (Mostafa et al., 2020; Oesterreich and Teuteberg, 2019). BIM adoption barriers can broadly be categorized into barriers to preliminary BIM adoption and barriers to sustained BIM adoption (Kim et al., 2005; Proctor et al., 2013; Fixsen et al., 2005; Aarons et al., 2011; May, 2013; Linton, 2002). The barriers to preliminary BIM adoption are the obstacles that frustrate the declaration of interests and the preparatory efforts to explore the usage of BIM (Enegbuma et al., 2014; May, 2013; Poctor et al., 2013); while, the barriers to sustained BIM adoption refer to the obstacles that frustrate the continuous usage of BIM (Grover et al., 1995; Al-Mashari and Zain, 1999; Towers, 1994; Kim et al., 2005).

The identification of barriers to BIM adoption guides the development of BIM implementation strategies (Bodea and Purnus, 2018; Borrmann et al., 2018). Smith (2014) describes BIM implementation strategies as the various initiatives and approaches for promoting BIM adoption on construction projects in the construction industry. However, the effectiveness of BIM implementation strategies depends on how well the identified barriers are related to the implementation process (Kim et al., 2005; Proctor et al., 2013).

1.2 Research background

Challenges such as lack of cooperation, distrust, disharmony, disjointed information, lack of social exchange standards, lack of collaborative working practices, ineffective communication, the uncoordinated flow of information, and adversarial relationship are commonplace in the construction industry (Huang et al., 2008; Lohiya, 2012; Witt, 2012). The negative effects of these challenges on the performance of construction projects have resulted in project delay and disputes, project cost and time overrun, inaccurate and conflicting project information, and deficiencies in project quality (Alarcon and Mardones, 1998; Trigunarsyah, 2004; Wong et al., 2004; Chen and Kamara, 2008; Nielsen et al., 2009).

The solution to these challenges is integration and collaboration among the construction project participants; but efforts to ensure integration and collaboration among the construction project participants have been unrewarding as a result of the inefficiencies of the traditional construction management systems (such as critical path, critical chain, agile and adaptive management system) and the innovative construction management systems (such as lean, concurrent engineering, construction project supply chain management, and web-enabled project management system) in use by construction organisations and professionals (Odeh and Bettaineh, 2002; Baloi and Price, 2003; Meeampol and Ogunlana, 2006; Dainty et al., 2006; Le-Hoai et al., 2008; El-Razek et al., 2008). For instance, the traditional and innovative management systems are characterized by linear and overlapping project planning, non-collaborative procurement process (that is, traditional design-bid-build procurement process), development of project information in 2D, lack of platforms for information exchange and integration, lack of interoperable tools and technologies, the unreliability of work process, and inability to provide object-oriented modelling (Owen et al., 2006; Koskela et al., 2010; Kostalova et al., 2015; Bryde et al., 2013).

As a consequence, scholars such as Bjork (2003), Samuelson (2003), Scott et al. (2005), Wikforss and Lofgreen (2007), and Macdonald (2013) established that the solution to problems of inefficient construction management systems is the use of alternate systems. As noted by these scholars, the use of alternate system is capable of ensuring integration and collaboration among the construction project participants through the provision of collaborative work processes and platforms for developing, integrating and disseminating project information. With the introduction of Building Information Modelling (BIM) in the construction industry, BIM-enabled construction management system or BIM adoption on construction projects has been identified as the perfect system for ensuring integration and collaboration among the project participants – BIM supply chain members (BIM-SCM) (Yori, 2011; Love et al., 2014; Khalfan et al., 2015; Bouazza et al., 2015; Wang et al., 2017). The acceptance of BIM adoption on construction projects was based on the suitability of the BIM tools and processes as a collaborative work platform for project delivery because BIM utilizes object-oriented information models and uses BIM technologies to provide collaborative platforms for the integration and management of the design done by the BIM-SCM (Arayici et al., 2011; Mrettinen and Paavola, 2014; Love et al., 2014; Wang et al., 2017).

The adoption of BIM tools and processes on construction projects brings integration and collaboration among the BIM-SCM, which indirectly address the challenges of construction project delivery. However, there are adoption barriers to be overcome and there are implementation efforts and requirements to be made available in the construction industry. Although, BIM awareness is rapidly increasing in the developing countries on account of

BIM implementation being touted as having the potential to meet the needs of the construction industry (Rogers et al., 2015; Enshassi et al., 2016; Abdelhameed and Saputra, 2020). In spite of the BIM awareness, some countries, such as South Africa (Froise and Shakanlu, 2014; Mtya and Windapo, 2019; Akintola et al., 2020), Iran (Hoseini et al., 2016; Khanzadi et al., 2020; Marefat et al., 2019; Samimpay and Saghatforoush, 2020), and Nigeria (Hamma-Adama et al., 2018; Babatunde et al., 2020; Elijah and Oluwasuji, 2019), are lackadaisical in making available BIM implementation efforts and requirements.

Recently, pockets of BIM adoption have been reported among the large and international firms that are operating in the developing countries (Mehran, 2016; Khodeir and Nessim, 2018; Kumar and Neeraj, 2020). This phenomenon is a result of abundant resources and availability of BIM-competent professionals in these firms, but it could suppress the growth of the indigenous firms in the developing countries (Mehran, 2016; Bensalah et al., 2018). Similarly, this form of BIM adoption does not translate to a significant and sustained BIM implementation because it does not give a true representation of the local market in the developing countries. Additionally, the adoption of BIM for projects by large and international firms in the developing countries may force the indigenous small and medium organisations to imitate the large and international organisations, which could frustrate the growth of these small and medium organisations, as well as the growth and development of the construction industry in those countries (Tezel et al., 2020; Saka and Chan, 2020; Li et al., 2019). This implies that ensuring a significant and sustained BIM implementation in developing countries requires more than creating BIM awareness.

The prevalence of slow BIM adoption in countries, such as Malaysia (Ismail et al., 2017; Kong et al., 2020; Tahir et al., 2017; Mustaffa et al., 2017), Ireland (McAuley et al., 2017; McAuley Carroll, 2017), Poland (Zima et al., 2020), Italy (Osello et al., 2020), China (Cao et al., 2017; Herr and Fischer, 2019; Mostafa et al., 2020), and South Africa (Kekana et al., 2015; Amanda and Windapo, 2019) is of concern. In some of these countries, BIM implementation efforts, such as mandatory use of BIM for public projects, development of national BIM standards, and establishment of BIM centres, have been made to implement BIM. In countries, such as the United States, Canada, United Kingdom, Singapore, Spain, Portugal, and Sweden, BIM implementation efforts have manifested in the form of the establishment of a national BIM program, mandatory use of BIM for spatial validation of projects, development of a national BIM standard, development of BIM protocol and Integrated Project Delivery documents, and development of BIM guidelines (Cheng and Lu, 2015; Shirowzhan et al., 2020). BIM institutes have been established, BIM guidelines and standards have been developed, and BIM has become a mandatory requirement in the contractor selection process (Silva et al., 2016; Andres et al., 2017). This approach has limited the focus of BIM implementation to the industry level with little or no concern for the cultural, structural, and economic impacts of mandatory BIM submission at the organisational and project levels. This means that BIM implementation efforts in these countries are not all-inclusive and have brought about some setbacks, such as non-realization of BIM benefits, lack of full-scale BIM projects, adoption bottlenecks, and economic liability to small and medium organisations (Kassem and Succar, 2017; Shibani et al., 2020; Siebelink et al., 2020).

Various reasons are postulated for the ineffectiveness of the BIM implementation strategies employed in prevailing over BIM adoption barriers, and the incapability of these strategies in ensuring integration and collaboration among the BIM-SCM in the developed and developing countries. First, BIM was portrayed more as technology and rarely as a construction management system (Khanzadi et al., 2020; Poirier et al., 2015; Nath et al., 2015; Won and Lee, 2016). This took the focus of BIM adoption on construction projects away from getting the best levels of integration and collaboration among the BIM-SCM to the acquisition and utilization of software technologies. It also made scholars concentrate efforts on identifying barriers to BIM adoption as an innovative technology, whereas BIM adoption is a stage in the BIM implementation process that comprises of preliminary and sustained BIM adoption, and has barriers to both preliminary and sustained BIM adoption (Enegbuma et al., 2014; Mostafa et al., 2020; Rogers et al., 2015; Oesterreich and Teuteberg, 2019). According to Poctor et al. (2013), Kim et al. (2005), Yetton et al. (1999), Al-Mashari and Zain (1999), May (2013), and Linton (2002), the process of BIM implementation will only be complete and successful when the barriers to preliminary and sustained BIM adoption are fully considered and addressed.

Second, the strategies developed following the identification of the barriers to BIM adoption as an innovative technology, lack a multi-dimensional approach (Smith, 2014; Succar and Kassem, 2015; Lindblad and Vass, 2015; Shou et al., 2015; Cheng and Lu, 2015; Gerges et al., 2017; Ho and Rajabifard, 2016; McAuley et al., 2017; Andres et al., 2017), because these barriers were drawn primarily from the perspective of Technology Acceptance Theory or Diffusion of Innovation Theory (Son et al., 2015; Ahuja et al., 2020; Shirowzhan et al., 2020; Yuan and Yang, 2020; Qin et al., 2020; Elshafey et al., 2020). These theoretical perspectives provide limited insight into the BIM implementation process (Attewell, 1992; Miller et al., 2013; Lyytinen and Damsgaard, 2001). BIM implementation strategies become effective and provide multifaceted insights into BIM adoption when they have contextual, theoretical and empirical justification, and incorporate considerations for organisational differences, culture, contingencies, commitment, and capacities to sustain BIM adoption (Jung and Joo, 2011; Kim et al., 2005; Migilinskas et al., 2013; Miettinen and Paavola, 2014; Bui et al., 2016; Gu and London, 2010; Silva et al., 2016; Cao et al., 2017; Morlhon et al., 2014; Succar and Kumar, 2015; Zhu et al. 2014; Zhang, 2014; Cao et al. 2015; Zhu and Mostafari, 2017). It becomes important to justify the consensus of organisational perceptions of BIM implementation strategies contextually, theoretically and empirically since the implementation process requires organisations to make adoption decisions; and since the willingness of the organisations to assume responsibilities for implementation strategies depend on their understanding and contributions to the choice of implementation strategies (Rapert et al., 2002).

The consensus of organisational perceptions is important in the choice of implementation strategies to ensure cooperation from the organisations and harmony between the requirements of implementation strategies and the efforts of the organisation towards adoption (Rapert et al., 2002; Zmud and Cox, 1979). In the same way, the consideration of organisational differences, culture, contingencies, commitment and capacities in developing BIM implementation strategies is vital to ensuring the success of BIM implementation owing to the complexity of BIM adoption barriers and the complexity of the construction projects and BIM-SCM (Proctor et al. 2013; Migilinskas et al., 2013; Miettinen and Paavola, 2014; Bui et al., 2016; Kassem and Succar, 2017). Strategic planning of BIM adoption on construction projects will also address the issues of economic liability to small and medium construction organisations, BIM skills and competencies, and BIM workflow adaptation challenges (Borrmann et al., 2016; Pishdad-Bozorgi et al., 2018; Isaksson et al., 2016; Enshassi and Abuhamra, 2017; Btoush and Harun, 2017; Yusuf et al., 2016; Smith, 2014; Cheng and Lu, 2015; Cao et al., 2014; 2015; Alwan et al., 2017).

Finally, the strategies employed lack an operational structure that will strategically guide the utilization of BIM and the assessment of BIM performance on projects concerning the achievement of integration and collaboration as the ultimate benefit of BIM adoption, as well as economically justify investment in BIM and demand for BIM by clients on their projects (Samimpay and Saghatforoush, 2020; Miettinen and Paavola, 2014; Cao et al., 2015;

Beaumont and Underwood, 2015; Abdirad and Dossick, 2016; Abbas et al., 2016; Ghaffarianhoseini et al. 2017; Sawhney et al., 2017; Wong et al., 2017; Liu et al., 2017).

The economic viability of small and medium construction organisations is an important consideration in BIM implementation because the adoption of BIM by small and medium construction organisations is very important for the industry; as more than 96% of organisations in the industry are small and medium construction organisations, which makes the economic performances of small and medium construction organisations vital to the macroeconomic performance of the construction industry (Saka and Chan, 2020; Khanzadi et al., 2020; Li et al., 2019; Awwad et al., 2020). According to Miettinen and Paavola (2014), Zhu et al. (2014), Isaksson et al. (2016), and Zhu and Mostafavi (2017), different construction organisations require different motivation for BIM adoption based on their respective organisational characteristics. Not all construction organisations could survive the economic liability of BIM adoption owing to their poor financial bases (Liu et al., 2017). Yet, nearly all the existing BIM implementation efforts lack supportive regulations, capacity development frameworks, and economic considerations, such as financial support towards BIM adoption for construction organisations that are not economically viable. This has been a major challenge of BIM implementation (Yusuf et al., 2016; Cheng and Lu, 2015).

For these reasons, it becomes imperative to investigate the prevailing BIM implementation strategies in the South African construction industry, establish whether the prevailing BIM implementation strategies are bringing about a reduction in the BIM adoption barriers, find the evidence of the application of BIM tools and processes on construction projects, and substantiate the impact of BIM adoption on the occurrence of integration and collaboration among the BIM-SCM. More important is the need to examine the barriers to preliminary and sustained BIM adoption and investigate BIM implementation strategies that will effectively address barriers to preliminary and sustained BIM adoption, incorporate a multi-dimensional approach, and provide guidance on the strategic planning of BIM adoption on construction projects for maximum derivable benefits, the minimum cost of BIM adoption, and the desired integration and collaboration among the BIM-SCM.

Therefore, this research will examine the critical barriers to BIM adoption on construction projects in an effort to identify appropriate strategies that could be employed in mitigating the barriers, while the usefulness of the strategies in facilitating integration and collaboration among the BIM-SCM will be examined in this research to propose techniques for strategic planning of BIM adoption on construction projects and as a standard for measuring the success of construction projects, the success of BIM-enabled construction management systems, and the performance of the BIM-SCM.

1.3 Problem statement

Integration and collaboration among the project participants – BIM supply chain members (BIM-SCM) –is the ultimate goal of project management and determines the choice of the construction management system. Integration and collaboration among the project participants are tied to the success of construction projects, the performance of the BIM-SCM, and the efficiency of the construction process. Scholars view that Building Information Modelling (BIM) is an effective collaborative work platform and system that brings about integration and collaboration among the BIM-SCM. However, the adoption of BIM on construction projects is not widespread, while there is no strategically structured BIM adoption guide available on construction projects for ensuring integration and collaboration among the BIM-SCM. The lack of adoption of BIM on construction projects has been adduced to the use of ineffective BIM implementation strategies. Furthermore, these strategies are not based on an in-depth investigation of the barriers to sustained BIM adoption and the non-usage of a multi-dimensional approach.

Therefore, this research examines the barriers to preliminary and sustained BIM adoption, the use of the multi-dimensional approach to BIM adoption, towards developing a framework that will facilitate BIM adoption on construction projects and the best levels of integration and collaboration among the BIM-SCM.

1.4 Research question

The main question investigated in this research was:

What BIM implementation strategies will result in sustained BIM adoption practices and the best levels of integration and collaboration among the BIM supply chain members?

1.5 Research aim

This research examines the barriers to BIM adoption on construction projects and whether there are specific BIM implementation strategies that will bring about sustained BIM adoption practices and the best levels of integration and collaboration among the BIM supply chain members.

1.6 Research objectives

The specific objectives are to:

i. Identify the BIM implementation strategies for driving BIM adoption on construction projects;

ii. Establish the indicators of a reduction in barriers to preliminary and sustained BIM adoption on construction projects;

iii. Establish the level of BIM adoption on construction projects;

iv. Determine the levels of integration and collaboration among the BIM supply chain members; and

v. Develop a model of the interactions between the levels of integration and collaboration among the BIM supply chain members, the level of BIM adoption on construction projects, reduction in barriers to preliminary and sustained BIM adoption on construction projects, and BIM implementation strategies.

1.7 Limitations and scope of the research

The use of the questionnaire survey limited the accuracy of the findings of the study owing to the reliance on the knowledge and experience of the construction professionals and subcontractors in South Africa. However, the effect of the limitation was significantly reduced by grouping the questions by research objectives, asking questions that engaged the research participants, making the questionnaire survey anonymous, and ensuring that the answer options were not leading. This research involved only self-reported BIM-based construction projects and the construction professionals and subcontractors, who worked on the projects in South Africa.

1.8 Significance of the research

The findings of this research led to an understanding of the barriers to BIM adoption on construction projects, and strategies that would reduce the barriers to BIM adoption on construction projects in South Africa. The information provided by this research on BIM implementation strategies and strategic planning of BIM adoption on construction projects is useful in bringing about the best integration and collaboration among construction project supply chain stakeholders on construction projects in South Africa. Also, the research has produced knowledge that is applicable to BIM adoption research works in developing countries, capable of changing the terms of the debate on BIM implementation policy formulation, and capable of promoting the uptake of BIM among the construction organisations in South Africa.

1.9 Outline of the Thesis

The thesis is structured into seven chapters as follows:

Chapter 1 presents the research context, research background, research question, research aim, research objectives, research scope, and the significance of the research.

Chapter 2 provides the overview of past studies on the Building Information Modelling (BIM) implementation strategies for driving BIM adoption on construction projects, indicators of a reduction in barriers to preliminary and sustained BIM adoption on construction projects, level of BIM adoption on construction projects, and levels of integration and collaboration among the BIM supply chain members. The chapter also provides the theoretical background for the interrelationships between the BIM implementation stages.

Chapter 3 explains the rationale for conducting this research. It presents information on the theoretical insights, theoretical framework, conceptual framework, and conceptual background that were employed in this research.

Chapter 4 explains the research philosophy, research paradigm, research design, research methods, research ethics, questionnaire design, interview design, data collection methods, data analysis methods for the quantitative data, and data analysis methods for the qualitative data.

Chapter 5 presents the analysis of BIM-based construction projects (BBCPs) involved in by the research participants. The chapter covers the conceptual framework that was employed for investigating the pattern of BIM adoption for the BBCPs. In addition, the chapter outlines the path analysis (reliability, validity, and consistency analysis) of the measured variables or measurement models for the barriers to preliminary BIM adoption on construction projects, barriers to sustained BIM adoption on construction projects, and BIM implementation strategies that are employed to trigger a reduction in the barriers to preliminary and sustained BIM adoption on construction projects. The chapter also presents the path analysis of the measured variables for the indicators of a reduction in barriers to preliminary and sustained

BIM adoption on construction projects, level of BIM adoption on construction projects, levels of integration and collaboration among the BIM supply chain members, and BIM implementation strategies that are required to trigger a reduction in the barriers to preliminary and sustained BIM adoption on construction projects. The chapter describes the parameter estimates and fit indices for the structural equation models of the relationship between BIM implementation strategies and the level of BIM adoption on construction projects, the relationship between BIM implementation strategies and barriers to preliminary and sustained BIM adoption, the relationship between the level of BIM adoption on construction projects on the levels of integration and collaboration among the BIM supply chain members, and the relationship between a reduction in barriers to preliminary and sustained BIM adoption (on construction projects) and the level of BIM adoption on construction projects.

The chapter also explains the structural equation modelling of the effects of BIM implementation strategies and a reduction in barriers to preliminary and sustained BIM adoption (on construction projects) on the level of BIM adoption on construction projects. Lastly, the chapter presents the structural equation model of the interactions between the levels of integration and collaboration among the BIM supply chain members, the level of BIM adoption on construction projects, reduction in barriers to preliminary and sustained BIM adoption on construction projects, and BIM implementation strategies.

Chapter 6 presents the interpretations for the integrated findings from mean item score analysis, thematic analysis, and structural equation modelling.

Chapter 7 serves as the concluding part of the thesis. It presents the summary of the research questions, results and findings, conclusions on findings, contribution to knowledge, recommendations, and areas for further research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of past studies on the Building Information Modelling (BIM) implementation strategies for driving BIM adoption on construction projects, indicators of a reduction in barriers to preliminary and sustained BIM adoption on construction projects, level of BIM adoption on construction projects, and levels of integration and collaboration among the BIM supply chain members. Efforts were made in this chapter to highlight the non-working and invalidity of the claims and findings reported by past studies. The chapter also provides the theoretical background on the relationship between BIM implementation strategies and level of BIM adoption on construction projects, the relationship between BIM implementation strategies and reduction in BIM adoption barriers, the relationship between reduction in BIM adoption barriers and level of BIM adoption on construction projects, and the relationship between the level of BIM adoption on construction projects and levels of integration and collaboration among the Building Information Modelling supply chain members (BIM-SCM).

2.2 Overview of past studies

This section presents the general review of literature on the Building Information Modelling (BIM) implementation strategies for driving BIM adoption on construction projects, indicators of a reduction in barriers to preliminary and sustained BIM adoption on construction projects, level of BIM adoption on construction projects, and levels of integration and collaboration among the BIM supply chain members.

2.2.1 BIM implementation strategies

The process of ensuring BIM adoption on construction projects has been described as BIM implementation (Ahuja et al., 2020; Babatunde et al., 2020; Lindblad and Guerrero, 2020; Shirowzhan et al., 2020; Mostafa et al., 2020; Siebelink et al., 2020). However, as observed by Cao et al. (2018), the process of BIM implementation places high requirements on the technical capability of organisations and professionals. This becomes the case because BIM implementation is important to construction organisations, construction professionals, and construction projects.

For the construction organisations, BIM implementation will enhance the global competitiveness of indigenous construction organisations, offer the best way to ensure quality works and workers efficiencies, and transform the intra- and inter-organisational relationships and settings (Papadonikolaki, 2018). Also, BIM implementation affects the established reward system, risk management, conflict management, and contractual relationships in construction organisations. It will also require construction organisations to constantly train their employees on BIM adaptation in terms of process, procedures, and policies (Lindblad and Guerrero, 2020).

BIM implementation presents an opportunity for construction professionals to integrate project-based relationships network structures, integrate project expectations and outcomes, as well as achieve better performance, improve the skills and competencies of construction professionals, and adapt to a new way of working (Cao et al., 2018). Also, BIM implementation will alter the roles, responsibilities, authorities, interests, and tasks of the project team members. For construction projects, BIM implementation will substantially reshape project design, construction process and activities, project delivery systems, and project information development (Liao and Teo, 2018).

The BIM implementation process requires an organized effort to provide the driving factors and forces for BIM adoption in the construction industry, by construction professionals, and on construction projects. The method for organising BIM implementation efforts is referred to as BIM implementation strategies. Some authors have provided definitions for BIM implementation strategies. Papadonikolaki (2018), Lee et al. (2019), and Cao et al. (2016) explained BIM implementation strategies as a set of financial, legislative, organisational, and technological initiatives for driving BIM adoption or institutionalizing BIM application. The above descriptions of the BIM implementation model highlighted driving forces, initiatives, and efforts as the elements of BIM implementation strategies.

The need to investigate useful and appropriate BIM implementation strategies becomes essential for so many reasons. First, BIM adoption is still plagued with different forms of barriers that must be eliminated before a consistent and practical BIM adoption can be achieved globally (Kim et al., 2017; Liao et al., 2019; Saka and Chan, 2020). Second, a comprehensive set of BIM implementation strategies is required to provide the necessary support, policies, strategies, legitimacy, incentives, resources, and guidelines for driving BIM adoption globally (Enegbuma and Ali, 2011; Vidalakis et al., 2020). Third, the growth of the construction industry, economic performance of construction organisations, and capacity development of construction organisations must be addressed through the appropriate BIM implementation strategies (Ahuja et al., 2020). Fourth, the effects of BIM adoption on the activities, characteristics, relationships, and management requirements must be mitigated (Akintola et al., 2020).

Recently, many studies have attempted to develop and investigate the BIM implementation strategies that would be useful and appropriate for driving BIM adoption. These studies cut across BIM implementation strategies for different BIM adoption (Underwood, 2019; Koseoglu and Nuran-Gumes, 2018; Cabonari et al., 2018), different countries (Lindblad and Guerrero, 2020; Cao et al., 2018; Liao and Teo, 2018; Papadonikolai, 2018; Yang and Chou, 2018; Junior et al., 2020; Le et al., 2018; Sanchus-Pedregosa et al., 2020; Bhatti et al., 2018; Odubiyi et al., 2019; Pillay et al., 2018), and different continents (Panteli et al., 2020; Olawumi and Chan, 2019). Studies on BIM implementation strategies for different BIM adoption have focused on BIM competencies (Pillay et al., 2018; Liao and Teo, 2018), construction site activities (Koseoglu and Nuran-Gumes, 2018), and facilities management task efficiency (Edirisingbe et al., 2016; Cabonari et al., 2018). Appropriate BIM implementation strategies have either been proposed or investigated for countries, such as Sweden (Lindblad and Guerrero, 2020), China (Herr and Fischer, 2019), Singapore (Oo, 2014; Liao and Teo, 2018), the Netherlands (Papadonikolai, 2018), Taiwan (Yang and Chou, 2018), Brazil (Junior et al., 2020), Vietnam (Le et al., 2018), Peru (Sanchus-Pedregosa et al., 2020), Pakistan (Bhatti et al., 2018), and South Africa (Odubiyi et al., 2019).

Some of these studies have differentiated between the appropriate BIM implementation strategies to be adopted by the government, industry leaders, and organisational leaders (Lindblad and Guerrero, 2020; Yang and Chou, 2018). Others have investigated the appropriate BIM implementation strategies through the use of theoretical perspectives, such as social capital theory (Cao et al., 2018), loosely coupled systems (Papadonikolai, 2018), activity theory modified with the diffusion of innovation theory (Le et al., 2018), and unified theory of technology acceptance (Sanchus-Pedregosa et al., 2020). At the continental level, Panteli et al. (2020) investigated the integration of BIM implementation initiatives into the national legislation of European member states.

Studies that have conceptualized BIM implementation strategies for driving BIM adoption include Herr and Fischer (2019), Olawumi et al. (2018), Yang and Chou (2018), Zhou and

Yang (2019), Puolitaival et al. (2016), and Haron et al. (2015). The study by Yang and Chou (2018) investigated the BIM implementation strategies in use by the government of Taiwan. The study reported that BIM implementation strategies in use in Taiwan represent a mixed approach of government-driven and industry-driven BIM implementation policies, such as BIM mandate, the publication of BIM implementation guides, provision of support to universities to provide BIM education, and hosting of BIM conferences. Similar studies were conducted in New Zealand and Malaysia by Puolitaival et al. (2016) and Haron et al. (2015), respectively. The BIM implementation strategies reported by Puolitaival et al. (2016) include BIM training, networks and communication, BIM guidelines, and BIM project examples. Haron et al. (2015) identified the need to promote the understanding of BIM in the construction industry, establish a BIM task force, and the development of national BIM guidelines as the BIM implementation strategies for accelerating BIM adoption in Malaysia. Table 2.1 presents a summary of the strategies for driving BIM adoption in the BIM implementation process.

Table 2.1: Strategies and initiatives for driving BIM adoption in BIM implementation process

Strategies for driving BIM adoption in BIM implementation process	References
Government guidelines and policies, practical standards and guidelines	Herr and Fischer, 2019
Development of expertise and awareness, development of capacity, top management commitment	Olawumi et al., 2018
Free intellectual property rights, assessment of BIM skills in the industry, encouraging BIM best practices, setting up scientific research incentives, develop appropriate BIM contract templates, supplemental contractual provisions for BIM adoption, provision of financial support for BIM implementation, aggressive promotion of BIM cooperation and collaboration	Zhou and Yang, 2019
Client demand for BIM, proper organisational structure, financial aid from the government, willingness of staff members to learn and utilise BIM	Chan et al., 2019
Top management support, staff training, clients demand for BIM	Oo, 2014
BIM standards system, BIM commercial model, BIM contribution to sustainability, optimal use of BIM	Bo et al., 2015
Initiatives for driving BIM adoption in BIM implementation process	
Software interoperability, selection of BIM tools, employment of pilot project, risks management, development of BIM guidelines and standards	Hanafi et al., 2016
BIM committees, BIM guidelines and standards, BIM training, financial support for BIM adoption, BIM pilot projects, internal BIM plans, collaborate with research institutions	Siriwardhana et al., 2018; Mustaffa et al., 2017
Technology infrastructures, objectives and stages milestones, champions and drivers, regulatory framework, noteworthy publication, learning and education, measurements and benchmarks, standardised deliverables	Succar and Kassem, 2015

Studies, such as Lindblad and Guerrero (2020), Siriwardhana et al. (2018), Hanafi et al. (2016), Hooper (2015), Cheng and Lu (2015), Mustaffa et al. (2017), Succar and Kassem (2015), and Edirinsinghe and London (2015), have also addressed BIM implementation from the point of view of initiatives. For example, Lindblad and Guerrero (2020) explored the appropriate initiatives for promoting BIM implementation by the public client in Sweden. The study found that demanding BIM in procurement and promoting competition among construction organisations are initiatives for promoting BIM adoption. It was concluded by the study that the promotion of BIM adoption by the public client will increase industry efficiency and that the influence of the public client on procurement as the major construction client is essential for driving BIM adoption.

Hooper (2015) studied BIM standardization efforts and needs in Sweden. The study identified national BIM guidelines, development of classification, coordination of information structure of BIM, format standards, and public procurements as the initiatives that are important to BIM adoption. The study by Edirinsinghe and London (2015) revealed that national governance and institutional frameworks are the standardization efforts that influence BIM adoption. Edirinsinghe and London (2015) concluded that the proliferation of national standards and compliance will ensure a widespread BIM adoption. Liu et al., (206) BIM guideline or BIM execution plan provides a framework for planning BIM adoption. The existing BIM execution plans include BIM guidelines for municipalities in New York City (Bloomberg et al., (2012), BIM execution plan in the Czech Republic (Hrdina and Matejka, 2016). BIM execution planning guide for contractors, specialty contractors, and designers (Manenti et al., 2020), BIM execution plan procedure for mega construction projects (Hadzaman et al., 2016), BIM execution plan for BIM model management during the pre-operation phase (Pruskova and Kaiser, 2019), and BIM execution planning in green building projects (Wu and Issa, 2015).
Specifically, Bloomberg et al., (2012) developed BIM guidelines for the development and use of BIM across multiple building types for municipal agencies in New York City (NYC). The objective of the guide is to ensure uniformity in the use of BIM for public building projects in NYC. The provisions in the guide cover the end-use of the BIM for multiple client agencies and the system of tailoring municipal agencies' requirements and standards to BIM. The study concluded that the guide will be reviewed and updated with advancement as more

insights emerge on the use of BIM. Hrdina and Matejka (2016) explained the main chapters of the Czech Republic's BIM execution plan and their benefits for BIM project in the Czech Republic. The existing BIM execution plans have provided the understanding of the planning of BIM application on construction projects. However, the existing BIM execution plans did not pay explicit attention to the strategy of BIM adoption on construction projects. This seems to be a great omission because a strategic BIM adoption will bring about the minimisation of BIM adoption risks, derivation of BIM benefits, and successful adoption of BIM (Ramírez-Sáenz et al., 2018). Also, none of the BIM execution plans has drawn attention to the planning of BIM adoption in developing countries.

The findings of other similar studies are summarized in Table 2.1. The elements of BIM implementation strategies have also been abstracted as driving forces for BIM adoption (see Table 2.2). The study of Liu et al. (2015) speculated on the appropriate driving forces from the government to promote BIM implementation. It was suggested in the study that improved national standards encourage BIM education and training, and mandatory BIM application is the force required to guide and lead towards BIM adoption in the BIM implementation process. In Ireland, McAuley and Carrol (2017) reported that the use of corporate resources, client and end-user demand, project requirements and expectations, legislative regulation, and industry networks will drive BIM adoption among the small firms. Different sets of driving forces – procurement routes and guidelines, training and education, process data exchange, regulatory framework, pathfinder projects – were reported by Hore et al. (2017) for driving BIM adoption among the small firms in Ireland.

In Malaysia, Rogers et al. (2015) identified the key drivers for adopting BIM from the perspective of engineering firms as including adequate trained personnel, resolving legal matters, government promotion, government financial subsidy, industry encouragement, professional bodies encouragement, and mandatory use of BIM on public projects.

In the United Kingdom, Eadie et al. (2015) investigated the changes required to drive BIM adoption. The study concluded that client demand for BIM will substantially drive BIM adoption. Wong et al. (2011) compared the government roles in BIM implementation between the United States and Hong Kong. The study recommended that the establishment of BIM maturity policy for major projects, provision of expert support and assessment for BIM technologies, partnership with BIM vendors and professional associations, and incentives for BIM adoption will promote BIM adoption. The study further highlighted the steps to be taken by the government of Hong Kong towards BIM implementation. These include the establishment of BIM adoption policy and programme, open standard development, design information evaluation, the establishment of a BIM implementation department, adoption of BIM by all government departments, and liaison with global professional bodies.

Table 2.2: Driving forces for BIM adoption in BIM implementation process

Driving forces for BIM adoption in BIM implementation process	References
Perceived ease of use, perceived usefulness of BIM, behavioural change towards BIM adoption	Sanchis-Pedregosa et al., 2020
Effective leadership, availability of qualified staff, availability of software technologies	Ozorhon and Karahan, 2016
Financial motivations to use BIM, access to BIM hardware, software and services, BIM skill acquisition, ease of BIM use	Dainty et al., 2017
The need for competitive advantage, the need for technological sophistication, internal capacity of organisations, BIM knowledge	Bosch-Sijtsema et al., 2017
Support for and enforcement of BIM by the government, promotion of BIM training program, initiatives of the industry leaders	Zahrizn et al., 2013
A competitive business strategy, policy and regulation, support structure, upskilling and training	Edirisingbe et al., 2016
Contractual arrangement, ICT literacy, staff cooperation, awareness of BIM guidelines and standards, capacity building for BIM implementation, behavioural changes from professionals, competitiveness	Olugboyega and Aina, 2016
Top management commitment	Ding et al., 2015; Son et al., 2015
Adequate trained personnel, resolving legal matters, government promotion, government financial subsidy, industry encouragement, professional bodies encouragement, mandatory use of BIM on public projects	Rogers et al., 2015
Strategic initiatives, change management, cultural readiness, learning orientation, knowledge capability, network relationships, process management	Kahkonen and Keinanen, 2016
Image or social motives, reactive motives, project-based economic motives, cross-project economic motives	Cao et al., 2017
Skills, technologies, integrative marketing products, process re-engineering, behavioural re-engineering	Olatunji, 2011

BIM competence, effective leadership, availability of qualified staff, and availability of software technologies were identified as the critical driving forces for BIM implementation in developing countries by Ozorhon and Karahan (2016). A literature review was conducted by Harun et al. (2016) towards understanding the required driving forces for BIM implementation globally. The extensive review led to the conclusion that, in countries where

BIM is thriving, the government had given full support and had provided supportive policies for BIM implementation.

The forces that will drive organisational change for BIM adoption and BIM adoption in project design have been reported by Brian and Prasharith (2017) and Son et al. (2015). The findings by Brian and Prasharith (2017) indicate that change agent effectiveness, communicated benefits, measured benchmarks, realistic timescale, senior leadership commitment, and provision of training resources will drive organisational change for BIM adoption. Son et al. (2015) concluded that the perceived usefulness and ease of use will increase the success of BIM implementation for project design.

More recently, Bakogiannis et al. (2020) investigated the strategies that are essential for driving BIM adoption in Greece. The study showed that the roadmap to a widespread BIM adoption in Greece requires the determination of a strategic BIM implementation plan, development of a national legal framework, management of project category, creation of evaluation system, measurement of integration of BIM tools, creation of stakeholders' network and marketing strategies, integration of BIM in education, and promotion of financing tools for BIM adoption.

The efforts, initiatives, and driving forces for BIM adoption as identified to be the constituents of BIM implementation strategies by these past studies are in isolation from one another and not integrated. These shortcomings have made the proposed BIM implementation strategies non-comprehensive and ineffective in driving a practical and consistent BIM adoption. BIM implementation is important to construction organizsations, professionals, and projects. This means that a comprehensive set of BIM implementation strategies is required to appropriately address the economical, relational, growth, resources, competence, capacity, and professional needs of construction professionals, organisations, and projects.

2.2.2 Indicators of a reduction in barriers to preliminary and sustained BIM adoption on construction projects

There is a dearth of literature on the reduction in barriers to BIM adoption on construction projects. Studies on barriers to BIM adoption have focused mainly on defining and identifying the BIM adoption barriers. Numerous studies have put forward different definitions of BIM adoption barriers. Enshassi et al. (2019) define BIM adoption barriers as the obstructions to the widespread adoption of BIM among construction practitioners. The definition of BIM adoption barriers, according to Chen and Ni (2019), describes BIM adoption barriers as the BIM implementation limitations that are impeding BIM adoption and are devoid of solutions. In the opinion of Ma et al. (2019), BIM adoption barriers are the challenges that are hindering successful BIM implementation across the construction industry and successful BIM adoption on construction projects. Boton et al. (2020) explained BIM adoption barriers as the issues, excuses, difficulties, and reasons that are obstructing BIM implementation and adoption. Altogether, these definitions suggest that, for a significant and successful BIM implementation and adoption, the essentials of BIM adoption barriers must consist of the difficulties with BIM adoption (that is, unknown barriers that will only be known and resolved when BIM is adopted) and obstacles to BIM adoption (that is, known barriers that had been resolved prior to BIM adoption).

Also, the definitions of BIM adoption barriers indicate that, apart from preventing the acquisition of BIM capacity, BIM adoption barriers are making BIM adoption difficult by inhibiting the performance of BIM and acquisition of BIM experience through non-consistent BIM adoption on projects. In other words, difficulties with BIM adoption are the issues with the performance of BIM on projects and are the major reason for non-consistent adoption of BIM on projects. Having difficulties adopting BIM on projects suggests that BIM adoption is largely on a preliminary or trial basis worldwide. Therefore, ensuring a consistent or sustained BIM adoption will require the development of proven solutions to the difficulties with BIM adoption (Nanajkar and Gao, 2014). However, most of the studies on BIM adoption barriers have focused only on the obstacles to BIM adoption using different perspectives (Oesterreich and Teuteberg, 2019; Arunkumar et al., 2018; Dainty et al., 2017), different research methods (Al-Yami and Sanni-Anibire, 2019; Stanley and Thurnell, 2014), and different construction organisations (Bosch-Sijtsema et al., 2017; McAuley and Carrol, 2017).

Some studies have attempted to identify the obstacles to BIM adoption based on different forms of BIM adoption, such as barriers affecting BIM adoption on prefabricated construction (Tan et al., 2019), barriers affecting BIM adoption in the design phase (Chan, 2014), barriers affecting BIM adoption for interior design (Hamid et al., 2017), barriers affecting BIM adoption for site health and safety management (Swallow and Zulu, 2019; Nnaji and Karakhan, 2020), and barriers affecting BIM adoption in renovation processes (Elagiry et al., 2019). Studies have also focused on barriers affecting BIM adoption among local contractors (Fitriari et al., 2019; Li et al., 2019; Pretti, 2016), facilities management

(Codinhoto et al., 2013; Jupp, 2013), construction project and site management (Al-Zwainy et al., 2017; Boton et al., 2020), higher education (Shibani, 2020), sustainable design and construction (Olawumi et al., 2018; Olawumi and Chan, 2020), nD BIM (Tse et al., 2005; Stanley and Thurnell, 2014; Kassem et al., 2012), and civil engineering projects (Kenley et al., 2016).

Existing studies, such as Ullah et al. (2019), Cao et al. (2019), Enshassi et al. (2019), Jamal et al. (2019), Zhao and Piennar (2019), Chan et al. (2019), and Siddiqui et al. (2019), have reported a handful obstacles as the significant BIM adoption barriers for wide-ranging BIM adoption. For example, Siddiqui et al. (2019) concluded that lack of skilled personnel, unwillingness to share information, legal and security issues, and the high cost of implementation are the major obstacles to BIM adoption. Chan et al. (2019) offered the resistance to change, inadequate organisational support and structure, and lack of BIM industry standards as the major obstacles to BIM adoption. Liu et al. (2015) identified the obstacles to BIM adoption as including high cost, lack of national standards, and lack of skilled personnel. Zhao and Piennar (2019) further list the lack of BIM implementation data in the construction phase, reluctance to openly share information, lack of industry standards, lack of tangible benefits, lack of demand for BIM use, and poor interoperability among BIM software. However, the concepts and conclusions of these studies did not convey a deep understanding of the difficulties of BIM adoption.

Recently, several studies have been conducted on BIM adoption barriers using theoretical perspectives. Oesterreich and Teuteberg (2019) identified the socio-technical barriers to BIM adoption using an information systems perspective. The study categorized the BIM adoption barriers as structural barriers, people barriers, technology barriers, and task barriers. Structural barriers were identified as including legal and contractual uncertainties, lack of client demand, lack of BIM awareness, lack of government incentives. According to the study, people barriers entail resistance to change, lack of expertise, lack of skilled personnel, lack of training, lack of trust, and lack of management support. Technological barriers entail lack of interoperability, insufficient infrastructure, BIM complexity, time-consuming adoption, lack of applicability and practicability, and poor quality of model information. Task barriers were identified as including high investment costs, lack of proven benefits, and lack of investment capital.

Using diffusion of innovation theory, Arunkumar et al. (2018) identified nineteen BIM adoption barriers. These include lack of support from senior management, lack of technical experts, high procurement cost, high training cost, learning curve, lack of supply chain buy-in, staff resistance, incompatibility between software platforms, product reliability risks, unavailability of process guidelines, and lack of mandate from the government. Others are indirect cost change, effects on initial productivity, culture change, satisfaction with current technology, fragmentation of the industry, resistance to honesty, lack of benefits, and low demand from clients. Dainty et al. (2017) investigated the barriers to BIM adoption by small firms using the digital divide theory. The study concluded that lack of usage opportunities, mandatory use of BIM, lack of BIM policy, and lack of BIM skills are the barriers to BIM adoption by small firms. Lastly, Chen and Ni (2019) reported social structures, levels of economic development, cultural and social trends, and cost as the barriers inhibiting the speed of BIM adoption. The study was based on the innovation diffusion theory.

A number of studies have argued that the BIM adoption barriers must be identified based on the forms of BIM adoption. Notable studies in this category were those by Olawumi et al. (2018) and Olawumi and Chan (2020), which investigated the barriers to BIM adoption in sustainable design and construction, and smart sustainable practices, respectively. A summary of the BIM adoption barriers identified based on the forms of BIM adoption is presented in Tables 2.3 and 2.4. Also, an extensive amount of research has been conducted on BIM adoption barriers in small construction organisations. For example, Bosch-Sijtsema et al. (2017) explored the perceived constraints of BIM adoption to small firms in Sweden. The study reported a lack of demand for BIM by clients, team members not using BIM, absence of internal demand in the small organisations, and negative evaluation of BIM as the BIM adoption barriers to small firms.

Likewise, McAuley and Carrol (2017) reported that the BIM adoption barriers for small firms in Ireland entail inadequate access to finance, inadequate knowledge and skills, fear of low success in adopting technology, poor level of communication and information exchange between parties in the construction process, and cultural change. Resources shortage, collaboration challenges, limited BIM awareness, legal disputes and uncertainties in policies, difficulties in meeting small and medium firms' needs, and concerns about data and information were identified as the barriers to BIM adoption in small construction organisations by Li et al. (2019) and Pretti and Vieria (2016).

Table 2.3: BIM adoption barriers based on forms of BIM adoption

Forms of adoption	**Major barriers**	**Reference**
BIM adoption in prefabricated construction	Inadequate BIM research and development, absence of standards and domestic-oriented tools	Tan et al., 2019
BIM adoption in the design phase	Insufficient qualified in-house staff, lack of training, lack of standards, lack of client demands	Chan, 2014
BIM adoption for interior design	Limited awareness, cost of adoption, lack of BIM knowledge	Hamid et al., 2017
BIM adoption for site health and safety management	Cost and time of training, cultural issues, lack of knowledge of the relationship between BIM and safety management, the extensive upfront investment required, need for extensive training before achieving optimum performance, concerns regarding the technical support availability, doubts regarding the reliability of BIM, lack of demand from clients, limited technology useful life	Swallow and Zulu, 2019; Nnaji and Karakhan, 2020
BIM adoption in renovation processes	Financial limitations, lack of BIM skills and knowledge, software limitations, poor renovation process practice, the scale of renovation work, lack of accuracy of the information about the existing building, lack of collaboration among the project participants	Elagiry et al., 2019
BIM adoption among subcontractors	The high cost of software and hardware, lack of BIM knowledge, lack of BIM awareness	Fitriani et al., 2019
BIM adoption in construction project management	Unspecified responsibilities for data content, lack of programs efficiency in data exchange	Al-Zwainy et al., 2017

Table 2.3: BIM adoption barriers based on forms of BIM adoption (cont'd)

BIM adoption in facilities management	inadequate awareness related to the benefits that BIM offers to facilities management practices, inadequate guidance on BIM implementation, skepticism about BIM value, inadequate best practices, entrenched work practice, asynchronous nature of facilities management knowledge integration, timeliness of training at handover, unknown facilities management data requirements, inappropriate technologies, skills shortages, inadequate verification and hand-over procedures, uncertainty in client-side facilities management strategy	Codinhoto et al., 2013; Jupp, 2013
BIM adoption in collaboration among the BIM supply chain members	Inadequate guidelines and standards on collaboration, data ownership and privacy concerns, lack of a common data environment, failures in technological support, interoperability challenges across the project lifecycle, complexities of adopting collaboration tools, inefficient BIM education on collaboration	Oraee et al., 2019
BIM adoption in sustainable design and construction	inadequate supporting sustainability analysis tools, non-implementation of open-source principle for software development, the inadequacy of BIM data schemes, inadequate support and involvement of the government, low level of involvement of BIM users in green projects, the inadequacy of requisite experience and knowledge and skills from the workforce, longer time in adapting to new technologies, increased risk and liability, limited legal framework and contract uncertainties, lack of suitable procurement policy and contractual agreements, inaccuracy and uncertainty in sustainability assessments for projects	Olawumi et al., 2018; Olawumi and Chan, 2020; Saka and Chan, 2020
BIM adoption in nD BIM data interfacing	Split between architecture design and drafting, inadequate objects and object customisation capability, complicated and time-consuming modelling process, lack of training and technical support, extra file acquisition costs	Tse et al., 2005
BIM adoption in 5D BIM	inadequate software compatibility, prohibitive set-up costs, lack of protocols for coding objects within building information models, lack of an electronic standard for coding BIM software, lack of integrated building information models	Stanley and Thurnell, 2014
BIM adoption in 4D BIM	Shortage of BIM experience, lack of awareness by stakeholders, inefficiency in the evaluation of the business value of 4D BIM, resistance to change, contract type	Kassem et al., 2012
BIM adoption for a light rail project	inadequate emphasis on the standardisation of data needs and requirements, the problem of information exchange between string-based and object-based design	Kenley et al., 2016
BIM adoption on construction sites	Technological versatility, performance issues, lack of capacity, resistance to change	Boton et al., 2020

Table 2.4: BIM adoption barriers based on country of studies

Country	Major BIM adoption barriers	References
Saudi Arabia	Inadequate of BIM policy, insufficient BIM research, resistance to change	Al-Yami and Sanni-Anibire, 2019
Iran	Inadequate legislative backing by government, inadequate subsidy for BIM software by the government, lack of training, cultural challenge, longer time to develop a schedule, BIM tools learning difficulties	Kiani et al., 2015
Gaza Strip	Inadequate commitment to adopting BIM for safety management, satisfaction with the existing safety planning tools and technologies, inadequate BIM knowledge, insufficient BIM guidelines for safety management, high cost of BIM software, insufficient time, BIM complexity	Enshassi et al., 2016
Malaysia	Inadequate BIM knowledge, reluctance to use BIM	Zahrizan et al., 2013
	Cost of the software and hardware, cost of staff training, resistant to change, high cost of applying BIM	Yaakob et al., 2018; Jamal et al., 2019
New Zealand	Incomplete design, insufficient model object data in the building information models, insufficient standards to facilitate electronic measurement, legal issues, lack of government support	Harrison and Thurnell, 2015
United Arab Emirates	Inadequate top management support, higher cost associated with BIM adoption, inadequate nationwide statutory support structure, lack of BIM professionals, inadequate information about BIM	Venkatachalam, 2017
Australia	Inappropriate information in building information model, incompatibility between BIM and existing asset management system, workflow disintegration, high cost of technology, insufficient industry push, the low priority placed on BIM, unawareness of current requirements	Edinsinghe et al., 2016
Colombia	Inadequate BIM knowledge, resistance to change, high cost of BIM adoption, insufficient BIM competent professionals	Gomez-Sanchez et al., 2016
China	Corporate leadership, project leadership, software functionality	Ma et al., 2019
India	Hesitation to adopt new technology, insufficient BIM experts, heavy initial cost, insufficient initiative and involvement from government	Kushwaha and Adhikari, 2016
Nigeria	Inadequate top management support, cost of BIM software and training issues, legal issues	Babatunde et al., 2020; Olanrewaju et al., 2020
	Inadequate awareness of BIM technology, inadequate expertise, inadequate collaboration by the stakeholders	Hamma-adama et al., 2019
South Africa	Inadequate BIM skills, inadequate BIM education, InadequateBIM knowledge	Kekana et al., 2015
	Insufficient organisational readiness, lack of client request for BIM	Amanda and Windapo, 2019

An alternative approach to BIM adoption barriers has been taken by several authors, such as Al-Yami and Sanni-Anibire (2019), Venkatachalam (2017), Amanda and Windapo (2019), and Ma et al. (2019). This has resulted in the identification of BIM adoption barriers according to the context of different countries (see Table 2.4). Similar to the shortcomings of other approaches, the contextual approach to the investigation of BIM adoption barriers did not reflect the complexity associated with the concept of BIM adoption and has not provided useful information in understanding the difficulties of BIM adoption. To a certain extent, it has further complicated the understanding of the obstacles to BIM adoption as a result of different BIM adoption barriers that were reported from the same country. For example, Yaakob et al. (2018) reported the cost of the software and hardware, cost of staff training, and resistance to change as the barriers to BIM adoption in Malaysia. These findings did not corroborate those of Zahrizan et al. (2013), who had earlier reported lack of BIM knowledge and reluctance to use BIM as the major BIM adoption barriers in the Malaysian construction industry. In China, the findings of Ma et al. (2019) were partially supported by those of Chen and Ni (2019). In Nigeria, the study by Babatunde et al. (2020) did not agree with Hamma-Adama et al. (2019). In South Africa, Amanda and Windapo (2019) identified a lack of organisational readiness and client request for BIM as the key barriers to BIM adoption. This conclusion did not support the conclusions of Kekana et al. (2015).

Further, BIM adoption barriers studies have also focused on the legal barriers to BIM adoption (McAdam, 2010), and barriers to the use of BIM implementation strategies (Zhou and Yang, 2019; Zhou et al., 2019). McAdam (2010) put forward interoperability, process, use of the model, status of the model, cost of BIM process, design liability, design delegation, ownership, and data protection issues as the legal barriers to BIM adoption. Zhou and Yang (2019) identified the barriers to the use of BIM implementation strategies to include insufficient government direction, legal issues, insufficient BIM motivations, and organisational issues. Zhou et al. (2019) identified insufficient leadership from government, organisational issues, cost of adoption, resistance to change, and insufficient motivation as the barriers to the use of BIM implementation strategies. Based on the analysis of the studies on BIM adoption barriers, it becomes evident that studies in the area of BIM adoption barriers provide conflicting findings which further support the need for a robust perspective for understanding the difficulties of BIM adoption.

2.2.3 Level of BIM adoption on construction projects

There exists a considerable body of literature on BIM adoption on construction projects. The BIM adoption literature can be classified as: frameworks exploring the possibilities of BIM adoption, models and case studies of BIM adoption, and literature reviews of BIM adoption.

Most of the BIM adoption literature has focused on developing frameworks for BIM adoption in design, construction, management, and integrated BIM.

Regarding frameworks for BIM adoption in design, studies, such as Ngowtanasuwan and Hadikusumo (2017), Hamieh et al. (2020), Alfieri et al. (2020), and Minunno et al. (2018), have made notable contributions. Ngowtanasuwan and Hadikusumo (2017) formulated policies for BIM adoption in system dynamics modelling of an architectural and engineering design. The study defined the policies as including BIM training, recruiting new staff members with BIM skills, employing design subcontractors, and setting up of a bonus programme for new BIM adopters. The study concluded that the policies would improve the BIM adoption performance of architectural and engineering design firms. Hamieh et al. (2020) proposed a BIM adoption system that is dedicated to automatic paths planning in a complex indoor environment. The system utilizes semantic, geometric, and typological features of the constituents of a BIM to generate navigation graphs that take the profile of mobile object or person and the operational accessibility status and spaces and transitions into account.

Minunno et al. (2018) investigated the possibility of adopting BIM for disassembly so as to improve the end-of-life de-construction phase of prefabricated buildings. Alfieri et al. (2020) developed a BIM-based approach for manufacturing design and assembly. The approach linked downstream activities, such as procurement, fabrication, transport, and installation, to upstream activities, such as brief, options appraisal, and concept design. The approach was tested using a case study. The study claimed that the approach serves as a guide for the production, collection, and organisation of data at each stage of design or manufacturing and assembly. It was concluded that the results of the case study confirmed the need for precisely structural procedures in delivering an off-site oriented project.

The study by Muhammad et al. (2020) is outstanding with respect to frameworks for BIM adoption in the construction process. Muhammad et al. (2020) employed BIM technologies, such as virtual reality for site layout optimisation. The study argued that three-dimensional-virtual reality-based site layout and organisation is more effective, easy to comprehend by users, and enhances the ability of collision detection. Studies, such as Cortes-Perez et al. (2020), Elghaish and Abrishami (2020), Jung et al. (2020), Ismail (2020), Ma et al. (2019), Jalilzadehazhari et al. (2019), Abed et al. (2020), Ratajczak et al. (2019), and Luo et al. (2018), have proposed frameworks for BIM adoption for construction management. Cortes-

Perez et al. (2020) proposed the methodology for integrating BIM in the management of occupational hazards in building construction and maintenance.

Elghaish and Abrishami (2020) proposed a framework for developing 4D planning and scheduling building information modelling. The study further developed a BIM library for automating the creation of the project schedule with respect to the 3D BIM sequence. The study claimed that the framework is useful for optimizing project duration by using a genetic algorithm model. Jung et al. (2020) proposed a prototype system for managing fire-related information using 3D visualisation tools of BIM. The study claimed that the system can automatically provide reliable fire-related information through a computerized and systematic approach, and the use of BIM tools. It was also claimed that the system will enable emergency responders to intuitively identify the location data of indoor facilities with its pertinent information based on 3D objects.

Ismail (2020) discussed the system approach for BIM application in the management of an industrialized building system. The study revealed the importance of BIM adoption in the maintenance management of complex and high-rise industrial building system buildings. This importance was argued to include faster defect diagnosis, quick decision-making, cost-effective maintenance, and easier defect control. Ma et al. (2019) proposed a BIM-based space management system for the operation and maintenance phase in educational office buildings. The system comprised of indoor space allocation management and indoor path navigation. The system allows the querying of the real-time space usage and matching of user demands with available space. A case study was conducted to validate the system, and the overall user satisfaction was 91.6%, as the space arrangement failures were greatly reduced. Jalilzadehazhari et al. (2019) exploited the use of BIM as a decision-making tool. It was claimed that using BIM in decision-making will create constructive communication between construction professionals, allow the analysis of the performance of multiple construction solutions with respect to visual and thermal comfort, and help to select a trade-off solution in the decision-making process.

Abed et al. (2020) examined the application of BIM technologies in improving the safety of Iraqi oil projects. It was argued that the adoption of BIM in oil projects will enhance safety analysis and will lead to accurate identification and assessment of hazards. It was concluded that applying BIM technologies in oil projects will increase the working duration of the projects and the total cost of safety equipment. Ratgczak et al. (2019) described a BIM-based augmented reality system for a location-based management system in construction management. The study argued that, if the functionalities of the system were adopted, it would be easy to detect scheduling deviations by visualising construction progress in augmented reality, provide daily progress and performance data of construction work, and monitor construction tasks in different locations. Luo et al. (2018) established a framework for BIM application in the whole life cycle of construction projects. The framework consists of a base layer database, data integration, and a corresponding model. The study posited that the framework will ensure information processing, cooperative-working, and improved project performance.

Outstanding efforts have been made to develop frameworks for integrated BIM by studies, such as Zhang et al. (2020), Wang et al. (2020), Wu and Lepech (2020), Tang et al. (2020), Machado and Vilela (2020), Jeong et al. (2016), Cerezo-Narvaez et al.,(2020), Cheng et al. (2020), Pakhale and Pal (2020), Li et al. (2019), Ayman et al. (2020), and Diakite and Zlatanova (2019). Zhang et al. (2020) developed an integrated method for managing BIM in 3D web-based GIS for hydraulic and hydropower engineering projects. The study claimed that the BIM and GIS integration platform is useful in addressing differences in geometric visualisation and coordinating transformation and rendering based on IFC formats and a 4 x 4 transformation matrix. The study further claimed that the platform is useful for building a new construction tool for hydropower project construction and that it offers a satisfactory scheme for resolving the inconsistencies in the storage, accuracy, and operational speed of the hydropower.

Wang et al. (2020) reported an integrated BIM approach that uses work package-based information modelling for capturing resource-constrained scheduling of construction projects. The study demonstrated the feasibility and efficiency of the method using an actual project and concluded that the method represents an opportunity to apply more complex and intelligent methods in project scheduling and material management. Wu and Lepech (2020) presented a framework that uses the application programming interface within BIM to integrate physics-based durability performance models. The framework extended the application of BIM into the post-construction phases by enabling more accurate predictions of life-cycle performance. The study claimed that the framework is useful for the analysis and management of a reinforced concrete structure, as well as integrating complex building deterioration models within a BIM environment.

Tang et al. (2020) proposed a BIM-enabled data conversion interface for 3D parametric modelling, structural calculation, and structural verification of asphalt pavement. The study concluded that the interface provides a support platform for the integration of BIM adoption in highway route design and pavement structural analysis. Machado and Vilela (2020) conceptualized a framework for integrating BIM and augmented reality (AR) in construction management. The framework identified fiducial markers, GIS/GPS, laser scanners, and photogrammetry as the main options for automatic data capture on the progress of the building site. The study concluded that BIM-integrated AR has the potential to solve information processing problems in construction management. Jeong et al. (2016) developed a framework for integrating BIM with construction operation simulation. The framework adopted Just-In-Time production management and identified a three-step application. The first step entails the preparation of a building information model to produce input data. The second step entails the composition of a construction simulation at the operational level. The third step deals with obtaining productivity dynamics from the BIM-integrated simulations.

Cerezo-Narvaez et al. (2020) conceptualised the system of generating and integrating cost breakdown structure with work breakdown structure in BIM environments. The study reported that the system reduces project contradictions at both planning and execution stages, anticipates potential schedule and budget deviations, improves resource allocation, and allows a better response to potential risks. Cheng et al. (2020) proposed a green building assessment method that combines the theory of life-cycle assessment and BIM technology. The method consists of the materialization stage, the operation and maintenance stage, and the demolition stage. The method was tested using a museum in Guangdong as a case study. The study claimed that the method plays an important role in reducing greenhouse gas emissions over the whole life-cycle of a building. Pakhale and Pal (2020) identified the potential of an integrated 5D BIM-based digital project management system for the Nagpur Metro Rail project in India. The study reported that reduced rework, reduced coordination problems, better communication between various stakeholders, reduced document errors, fewer claims, reduced paperwork, reduction in time and cost overrun, and reduction in life-cycle cost as the potentials of BIM adoption in rail project.

Li et al. (2019) proposed a framework for integrating BIM in prefabrication housing production. The framework involves smart BIM platforms, smart work packages, and smart prefabrication housing production objects. It was claimed that the framework can help the development of system architecture for BIM in prefabrication housing. Ayman et al. (2020)

developed BIM capability and a BIM-enabled sustainability application system. The system comprises representation, performance simulation, transaction and exchange, documentation, automation, and standardization. The study maintained that BIM can be adopted for documentation, evidencing requirements, progress monitoring, and decision-making in sustainable project delivery. Diakite and Zlatanova (2019) proposed a framework for automatic geo-referencing of BIM on GIS environments using building footprints. The framework is automatic and it allows the transformation of the local coordinates of a BIM model into its real-world geographic coordinates. The framework also applies a rigid motion transformation to a corresponding 2D projection generated from the BIM model in order to obtain the transformation matrix that will align the geometry of the BIM to the map's one. A summary of recent and existing studies on BIM adoption frameworks is presented in Table 2.5.

Globally, fewer studies have exclusively focused on the model and case studies of BIM adoption. For example, Jiang et al. (2020) demonstrated the utilization of 3D spatial information for hoist site mapping and 3D reconstruction of the site model in real-time. The study showed that the use of BIM for site mapping and site reconstruction can intelligently save planning time and provide a new solution to hoisting safety and efficiency. Huang (2020) reported a case study of the use of BIM as an innovative instructional tool to teach construction management students. The study claimed that BIM proved to be a useful tool for hands-on sessions in teaching and for instilling spatial skills in construction management students. Herr and Fischer (2018) examined the processes and models of BIM adoption in China. The study noted that current BIM adoption models did not allow for the differentiated assessment of different building life-cycles stages and quantitative assessment of the degree of adoption.

Olugboyega (2016) examined the protocols and platforms adopted for BIM processes by Nigerian construction professionals. The study reported that full collaboration was not practised among the construction professionals and that interoperable BIM platforms were not used on projects. Bui (2018) reported a qualitative case study of BIM adoption for a bridge project in Vietnam. The study claimed that the project team members considered the project a success. Park and Kim (2014) investigated the essential BIM input data for housing refurbishment in the United Kingdom. Although the study revealed that BIM adoption in housing refurbishment is experiencing difficulties as a result of a lack of a BIM dataset and objects for housing refurbishment. It was, however, concluded that BIM adoption in housing refurbishment is useful in understanding clients' value, which is needed to bridge the gap between their preferences and provide affordable refurbishment solutions. Sarvari et al. (2020) evaluated the impact of adopting BIM for the delivery of mass housing projects. The study maintained that BIM adoption was useful for integrating information, discovering and resolving spatial conflicts, simulating building energy consumption, examining safety issues in the construction process, monitoring the construction process and delivery, and capturing real-world building information.

A number of authors have also conducted extensive literature reviews of BIM adoption. For instance, Chang and Hsieh (2020) explained the potentials of BIM in green building design through building performance analysis. According to the study, the potentials of BIM in green building design include energy and thermal analysis, green building rating analysis, cost and benefit analysis, wind and ventilation analysis, acoustic analysis, and water efficiency analysis. Abdelbary et al. (2020) investigated the potentials of BIM in reducing client-related rework in fast-tracked construction projects in Egypt. The study identified visualization as the solution to client-related rework. It was concluded that BIM has the potential to reduce the cost of rework and schedule in fast-track construction.

Xu (2019) reviewed the literature to identify areas for BIM adoption in the operation and maintenance of large commercial complex architecture. According to the study, important areas for BIM adoption in the operation and maintenance are space management, equipment management, building intelligent monitoring, energy management, energy drill, and asset management. The study concluded that BIM adoption in the operation and maintenance for large commercial complex projects will solve the visualisation problem of logistic operation and maintenance, will add value to the project, and will ensure effective realization of lifecycle management of commercial complex construction and operation. Enegbuma et al. (2016) investigated the relationship between business process re-engineering, computer-integrated construction, and BIM adoption. The study reported that there is a high level of correlation between the business process re-engineering, computer-integrated-construction, and BIM adoption. The study further concludes that the high impact of business process re-engineering and computer-integrated construction on BIM adoption will positively affect the adoption rate of BIM.

A closer look at the BIM adoption literature reveals that previous studies have focused almost exclusively on the possibilities of BIM adoption for the various aspects of project delivery.

This indicates that there is a lack of a deep understanding of the levels of BIM adoption on construction projects. It also indicates a lack of extensive case studies of actual and practical BIM adoption on construction projects.

Table 2.5: BIM adoption frameworks

BIM adoption frameworks	**References**
Framework for constructing As-Is-BIM for existing buildings using image-based technologies	Lu and Lee, 2017
Semi-automatic framework for generating a semantic-rich structural building information models from two-dimensional computer-aided design drawings	Yang et al., 2020
Framework for automatic quantification of the dimensions of precast concrete bridge deck panels using laser scan data	Wang et al., 2018
Framework for conducting time and cost analysis of the geometric quality assessment of structural columns using three-dimensional terrestrial laser scan data	Guo et al., 2020
Framework for construction site layout optimization and three-dimensional visualization using BIM tools	Olugboyega and Wemimo, 2018
Framework for integrating BIM with blockchain technology to create an automated financial system	Elghaish et al., 2020
BIM-enabled framework for modular design and industrialized construction of mechanical, electrical, and plumbing systems using a three-dimensional laser scanner and robotic total station	Zhang et al., 2016
Framework for managing BIM adoption processes	Olugboyega, 2017a
BIM-enabled framework for project management	Kalfa, 2018
BIM-enabled framework for site layout optimization using three-dimensional virtual reality	Muhammad et al., 2020
Framework for connecting intrinsic heritage BIM database with heritage documentary databases using an innovative in-cloud system	Palomar et al., 2020
Framework for BIM application in construction delay management	Marzouk et al., 2018; Chou and Yang, 2017
Framework for automating the sustainability assessment for proposed buildings using BIM and LEED certification system	Jalaei et al., 2020
Framework for determining builders' roles in BIM adoption processes	Olugboyega, 2018

Table 2.5: BIM adoption frameworks (cont'd)

BIM adoption frameworks	References
BIM-enabled framework for asset management	Brunet et al., 2019; Alnaggar and Pitt, 2019
Framework for exploring the interplay between construction regulations and BIM	Mzyece et al., 2019
Framework for integrating BIM in the city and urban planning	Hijazi and Donaubauer, 2017; Hijazi et al., 2018
Framework for creating a BIM environment in AEC firms and projects	Olugboyega, 2017b
BIM-GIS integrated framework for planning water distribution system	Zhu et al., 2019; Zhuo et al., 2020
Framework for linking construction economic systems with BIM	Biolek et al., 2019
Framework for creating a cloud-BIM environment in AEC firms	Olugboyega et al., 2019
BIM-based framework for enhancing the knowledge and proficiency of interior designs	Hamid et al., 2020
BIM-LEAN framework for saving execution costs in building construction	Mahmood and Abrishami, 2020
Framework for achieving a critical value of BIM adoption in waste management	Liao et al., 2020
Framework for integrating BIM adoption with sustainable construction	Zhang et al., 2019
Framework for identifying schedule risks and providing an effective solution for schedule management	Rehman et al., 2020
BIM-enabled framework for applying the Last Planner System on construction sites	Boton et al., 2020
BIM digital twin framework for integrating building design, construction, and maintenance	Alonso et al., 2020; Lu et al., 2019
Framework for analysing the impact of BIM adoption on productivity in construction project management	Mesaros et al., 2020
Framework for integrating BIM with the RIBA plan of work	Amin and Abanda, 2019
BIM-enabled framework for assessing energy savings	McAuley et al., 2019
Semantic-based framework for BIM-enabled automated rule checking in healthcare construction projects	Soliman-junior et al., 2020
Framework for BIM adoption in tunnelling projects	Ninic et al., 2020
Semi-automated framework for dynamic information sharing processes using cloud-BIM	Abanda et al., 2018

2.2.4 Levels of integration and collaboration among the BIM supply chain members

In the construction industry, integration and collaboration have been used interchangeably to depict a process of homogenizing the project elements (that is, project documents and project participants). Although both terms are synonymous, they are also different (Koolwijk et al., 2018). Integration describes the process of coordinating project elements. The main objective of integration is to manage conflicts between the project elements by making the project participants work together and by making the project documents devoid of conflicts (Bayramoglu, 2001). Collaboration, on the other hand, describes a cooperative process in which project participants work together to produce a comprehensive project document, and to effectively deliver projects. The main objective of collaboration is to achieve an alliance of expertise, resources, purpose, knowledge, skills, experience, and priorities of the project participants (Sanders et al., 2005).

The result of the alliance in collaboration is to achieve a common purpose, cooperation, coordinated or joint efforts, productive disagreement and engagement, direct communication, creative and innovative solutions, and a sense of support (Shen et al., 2010). This means that integration and collaboration can be used together to describe the process of ensuring cooperation and coordination in project elements. In the process of developing project documents, the collaboration will provide joint efforts, while integration will connect the information and data in the project documents towards making them function as one (Shen et al., 2010; Sanders et al., 2005). This means that information and data contained in different project documents will become a part of comprehensive project documentation.

For the project participants that will develop the project documents, the collaboration will create teamwork and cooperation, while integration will bring about oneness and unity (Bedwell et al., 2012; Chiocchio et al., 2011). This explanation shows that collaboration is more of a cooperative process, but has an element of the coordination process because of the joint efforts that it provides. Integration is mainly a coordination process but becomes synonymous with collaboration because it has some elements of coordination. The agreement between integration and collaboration implies that both terms must go hand-in-hand and must be used as a single term in construction project delivery.

However, integration and collaboration have remained but a fantasy in the construction industry as a result of the traditional work process (Tulenheimo, 2015; Leite et al., 2016). In the traditional work process, project participants are expected to develop project documents according to their roles. They are not expected to collaborate on projects or integrate their project documents (Hwang and Ng, 2013). This process usually leads to inefficiencies on the part of the participants and deficiencies on the part of the project documents. The inefficiencies and deficiencies become more pronounced with the level of project complexity and differences in the sources and backgrounds of the project elements.

The harmony that integration and collaboration will create between the project elements have been identified as the solution to the deficiencies and inefficiencies of the traditional work process. According to Briscoe and Dainty (2005), the infusion of integration and collaboration into the traditional work process will breakdown the fragmentation and professional stereotypes that have become the norm in the construction industry. Van Leeuwen and Fridqvist (2006) described integration and collaboration as a critical success factor for project delivery. Recently, BIM adoption on construction projects has been described as providing the opportunity to infuse the traditional work process with integration and collaboration (Getuli et al., 2020; Kouhestani and Nik-Bakht, 2020; Zhai et al., 2019; Yuan and Yang, 2020; Wang et al., 2020). It was also explained that infusing the traditional work process with integration and collaboration through BIM will entirely create a new work process known as *BIM process*.

This indicates that the BIM process is now the new integration and collaboration because the concept of integration and collaboration is not new to the construction industry. It has only evaded the industry owing to the lack of effective means of infusing it into the work process. To illustrate BIM process as the new integration and collaboration, Alsheridi et al. (2018) explained that BIM adoption offers the project participants the opportunity to insert, update, modify, extract information, as well as interact, exchange, communicate, approve, and coordinate information during the BIM process. Based on the importance of integration and collaboration to project success, integration and collaboration have been identified as the most important benefits of BIM adoption (Zhai et al., 2019; Utkucu and Sozer, 2020; Baradi et al., 2018; Logothetis et al., 2018).

The explanations for this claim hinge on the fact that integration and collaboration represent the ultimate project success factor and result in an efficient and effective BIM process. As the ultimate project success factor, BIM-enabled integration and collaboration have been posited to optimize the project design (Liao and Teo, 2018), improve communication among the BIM supply chain members (Lui et al., 2017), enhance interoperability and trust development (Zheng et al., 2017), and create a non-adversarial team-based environment (Baradi et al., 2018). As the result of an efficient and effective BIM process, BIM-enabled integration and collaboration will manifest as a timely and real-time communication (Zhai et al., 2019), collective decision-making (Utkucu and Sozer, 2020), shared respects and understanding (Baradi et al., 2018), collective benefits and shared interests (Liao and Teo, 2018), risk-sharing (Liu et al., 2017), social interactions (Koseoglu and Nurtan-Gunes, 2018), and mutual support (Logothetis et al., 2018).

The literature on BIM-enabled integration and collaboration is limited. Much of the available literature has either proposed frameworks for BIM-enabled integration and collaboration or reported factors affecting BIM-enabled integration and collaboration. The frameworks for BIM-enabled integration and collaboration proposed by the existing studies have considered only cloud-based BIM-enabled collaboration, collaboration changes, and collaborative decision-making tools. For example, Logothetis et al. (2018) developed a cloud-based system for facilitating BIM-based collaboration between BIM supply chain members. The cloud-based system is useful for linking BIM tools and making them available to a large community of professionals. The system can handle geospatial data and support all stages of BIM processes.

Abanda et al. (2018) maintained that the use of cloud-BIM for construction management will ensure asynchronous collaboration – collaboration at the same place and collaboration at different times; distributed collaboration – collaboration at different places; synchronous collaboration – collaboration at the same time; and face-to-face collaboration. The features of these forms of collaboration were identified as including site meetings, posters, sketches, discussions, memos, emails, fax, telephone, video conferencing, and webinars. Leifgen et al. (2016) introduced a BIM-based collaboration platform for energy active façade components, such as building-integrated photovoltaic, and building-integrated solar thermal, components. The platform enables project participants to exchange data in a structured way and requires them to be able to handle open standards, manage design reviews, and link information within a building information model. Naticchia et al. (2020) proposed a framework that utilised BIM-enabled mixed reality and cloud platform to support information sharing and exchange in facility management. The framework explained the use of the BIM server, information flow management, automatic inventory, on-site testing, diagnosis support, and on-site operation support in the BIM-enabled facilities management system. The framework was developed to exploit all the benefits of BIM and achieve an improved level of efficiency.

Wang et al. (2020) proposed a framework for analyzing collaborative changes and relationship discovery among the BIM supply chain members for a rail project. The framework described the BIM-enabled collaboration attributes of the BIM supply chain members based on their activity level. The study verified the usefulness of the framework with a rail project named “Circle Line 6” in Singapore. It was concluded that BIM adoption on rail projects increased the weight of cooperative relationships among the BIM supply chain members. Bolshakova et al. (2020) proposed the use of 4D BIM as a collaborative decision-making tool. The study argued that the use of 4D BIM in decision-making will enable the understanding of project complexity, time management and project development relation, and information accessibility.

Ma and Ma (2017) formulated the application functional requirements of a BIM-based collaboration platform to support integrated project delivery (IPD) projects. The requirements entail thirty-eight functional requirements classified into documents, building information models, drawings, audio-visual information, and comprehensive information requirements. The study concluded that the formulated application functional requirements can be used in the development of a commercial collaboration platform to better support IPD projects. Cidik and Boyd (2020) explained how the shared sense of purposefulness will enable the design team members in a BIM supply chain to attain a temporary and precarious organisational state. The study further explained that attaining a state of a shared sense of purposefulness will improve design coordination and ensure social interaction.

The studies on the factors affecting BIM-enabled integration and collaboration have only provided theoretical evidence and no empirical evidence. For instance, Mignone et al. (2016) identified the factors inhibiting collaboration in BIM-based construction networks (BBCNs). The study was based on organisational discontinuity theory and conceptualized the BIM team as the BBCNs. Oraee et al. (2017) conducted a scientometric-qualitative literature review of collaboration on BBCNs. The study employed a “collaboration pentagon” of context, process, structure, agent, and artefact as a theoretical lens for the literature review. It was concluded in the study that there is a lack of information on the best practices for integration and collaboration as a BIM process. The study recommended that future studies must investigate the elements of BIM collaboration systems. Guo and Feng (2019) employed the “integration pentagon" of process, context, task, organisation, and actor as a theoretical lens for a mixed-method literature review of integration in BBCNs. The study concluded that there is a gap in the literature on BIM-based integration. Further, the study recommended the development of the concept of integration in BBCNs by future BIM studies.

Oraee et al. (2019) conceptualized the barriers to collaboration in BBCNs. The study conceptualized that process, actor, context, team, and task barriers are the factors affecting collaboration among the BIM team. In the study, Oraee et al. (2019) identified the process barriers to include the lack of common data environment, lack of collaboration guidelines, data ownership concerns, lack of technological support for collaboration, complexities of adopting collaboration, lack of BIM education on collaboration, and interoperability challenges. The actor barrier was described as insufficient collaboration knowledge and skills. The task barrier was described as the absence of the right information at the right time. The lack of understanding of the concept of collaboration, disparities in collaboration approach, lack of team working mentality, lack of a comprehensive and transparent contract, and fragmented nature of the construction industry were recognized as context barriers. Oraee et al. (2019) branded team barriers as isolated working mentality, resistance towards data and information sharing, unestablished working collaboration, competition for the role of BIM manager, and improper team structure and role allocation.

Despite two decades of research on BIM concept and adoption, the concept of BIM-enabled integration and collaboration has been assessed only to a very limited extent. Even the existing research on BIM-enabled integration and collaboration has many shortcomings. Firstly, no concept was provided to explain the elements of integration and collaboration as a BIM process. Secondly, the existing research has only theorized and argued on the occurrence of integration and collaboration in the BIM supply chain without providing any explanation for the nature of its occurrence. Also, the existing research on BIM-enabled integration and collaboration has pointed out the lack of understanding of the concept of integration and collaboration as a BIM process and lack of collaboration guidelines as major barriers to collaboration in the BIM supply chain. This underscores the need to investigate the concepts of integration and collaboration as a BIM process and provide empirical evidence for the occurrence of integration and collaboration in the BIM supply chain.

2.3 Theoretical background

This section presents the theoretical background on the relationship between BIM implementation strategies and level of BIM adoption on construction projects, the relationship between BIM implementation strategies and reduction in BIM adoption barriers, the relationship between reduction in BIM adoption barriers and level of BIM adoption on construction projects, and the relationship between the level of BIM adoption on construction projects and levels of integration and collaboration among the Building Information Modelling supply chain members (BIM-SCM).

2.3.1 Relationship between BIM implementation strategies and level of BIM adoption on construction projects

BIM implementation and BIM adoption are not the same but interrelated (Jin et al., 2015). Gerges et al. (2017) explained that BIM implementation may well be in an advanced stage, while BIM adoption may remain in its early stage in the same construction industry. BIM implementation is the process of ensuring BIM adoption in the construction industry, as it relates to the plans, policies, standards, and initiatives put in place for driving BIM adoption. According to Succar and Kassem (2015), BIM implementation makes provisions, requirements, and guidelines for BIM adoption. BIM adoption, on the other hand, refers to the formal acceptance of BIM by construction organisations and professionals as a working system (that is technology, process, and management) in the construction industry (McAuley et al., 2018; Hossain and Yeoh, 2018).

BIM adoption deals with the potentials and functions of BIM, which construction organisations and professionals may adopt in their work processes and on their projects (Mohammad et al., 2018). In a few words, BIM adoption is an outcome or the objective of BIM implementation; and the scope of BIM implementation is broader than that of BIM adoption because BIM implementation is the transition period of BIM adoption. These pieces of evidence indicate the existence of a relationship between BIM implementation and BIM adoption. However, this relationship is not linear and this is because BIM implementation is a complex phenomenon (Al Hattab and Hamzeh, 2018). Standardizing the relationship between BIM implementation and BIM adoption requires the use of appropriate BIM implementation strategies that will provide the necessary support, legitimacy, incentives, resources, and guidelines for BIM adoption by construction organisations and professionals (Fountain and Langar, 2018).

The implication of the link between BIM implementation and BIM adoption is that BIM implementation in the construction industry will only be deemed successful when BIM adoption is active at both the organisation level and the project level (Poirier et al., 2015). These explanations highlight successful BIM adoption as the target of BIM implementation and also draw attention to the fact that BIM adoption barriers are the challenges of BIM implementation (Miller et al., 2013; Silva et al., 2016). These barriers constitute the factors affecting BIM implementation, as well as BIM adoption, owing to their interrelationships. For example, Ghaffananhoseini et al. (2017) reported that the continued development of BIM tools and processes as well as the slow rate of transition from the traditional work process to BIM will affect the level of BIM adoption in organisations and projects. Attarzadeh et al. (2015) stated that the problem of finding the balance between the level of BIM adoption, the benefits from BIM adoption, project success, and project characteristics is a major barrier to BIM implementation and adoption.

Also, the levels of complexity of construction projects have been established to have a significant impact on the extent of BIM adoption on construction projects (Cao et al., 2015; Lattifi et al., 2013). This has led to the conclusion by Cao et al. (2015), which identified project size as a predictor of the extent of BIM adoption on construction projects. Similarly, Lattifi et al. (2013) illustrated the relationship between the levels of complexity of construction projects and the extent of BIM adoption on construction projects by suggesting that BIM-enabled multi-disciplinary collaboration is more suitable for highly complex projects because of their high risks and expectations. The need to make BIM implementation active at the industry level (macro), organisational level (meso), and project level (micro) was a major BIM implementation and adoption barrier as described by Poirier et al. (2015) and Papadonikolaki (2017).

Recently, studies have investigated the barriers to different forms of BIM adoption, such as BIM adoption in sustainable design and construction, BIM adoption on construction sites, BIM adoption for civil engineering projects, and BIM adoption for smart sustainable practices. For example, Olawumi et al. (2018) identified education, attitude, market, project, and organisational barriers as the barriers to BIM adoption in sustainable design and construction. Kiaini et al. (2015) found the barriers to BIM adoption in project planning and scheduling phase to consist of lack of legislative backing by government, lack of subsidy for BIM software by the government, lack of training, cultural challenge, longer time to develop a schedule, and BIM tools learning difficulties. Enshassi et al. (2016) concluded that lack of commitment to adopting BIM for safety management, satisfaction with the existing safety planning tools and technologies, lack of BIM knowledge, lack of BIM guidelines for safety management, high cost of BIM software, lack of sufficient time, and BIM complexity are the barriers to BIM adoption for safety improvement.

Elagiry et al. (2019) revealed that the barriers to BIM adoption for building renovations include limitation of financial resources, lack of skills and knowledge, limitation of BIM software for renovation projects, old-fashioned renovation practice, the scale of renovation work, lack of accuracy of the information about the existing building, and lack of collaboration among the project participants. Similarly, Olawuni and Chan's (2020) findings suggest that lack of supporting sustainability analysis tools, lack of support and involvement of the government, lack of framework and contract uncertainties, inaccuracy and uncertainty in sustainability assessments for projects, and longer time in adapting to new technologies are the barriers to BIM adoption in smart sustainable practices. Nnaji and Karakhan (2020) claimed that extensive upfront investment required, the need for extensive training before achieving optimum performance, concerns regarding the technical support availability, doubts regarding the reliability of BIM, lack of demand from clients, and limited technology useful life are the barriers to BIM adoption for construction health and safety management. Boton et al. (2020) established that BIM adoption barriers on construction sites include technological versatility, performance issues, lack of capacity, and resistance.

The reality of the barriers to BIM adoption and implementation as identified by these studies has influenced the recommendation of different BIM implementation strategies (Ahuja et al., 2020). The government and the industry leaders are saddled with the responsibilities of developing and initiating these strategies because BIM implementation is a national and industry issue (Liu et al., 2015). Although, the success of BIM implementation does not depend only on policies and plans initiated by the government and industry leaders towards BIM implementation and adoption, it also depends on the commitment of organisations' top management (Tezel et al., 2020). This implies a relationship between BIM adoption and BIM implementation and suggests that the efforts required to make the relationship linear are represented by the BIM implementation strategies.

2.3.2 Relationship between BIM implementation strategies and reduction in BIM adoption barriers

The objective of BIM implementation will be difficult or impossible to achieve until the BIM implementation strategies bring about a reduction in BIM adoption barriers. This means that the smooth flow of BIM implementation process requires a significant reduction in BIM adoption barriers (Enegbuma et al., 2015; Eadie et al., 2014; Zuhairi et al., 2014) and that the progress of BIM implementation process depends largely on how the thresholds or levels of reduction in BIM adoption barriers have been planned. In another words, the stage or status of BIM adoption, which is the objective of BIM implementation, cannot significantly manifest without a significant reduction in BIM adoption barriers.

Several studies have attempted to identify BIM adoption barriers that must be reduced or eliminated at both the industry level and organisational level before there can be a widespread BIM adoption on construction projects. For example, Yaakob et al. (2018) determined the barriers to BIM adoption in the construction industry of Malaysia to include the cost of the software and hardware, cost of staff training, and resistance to change. Further research by Jamal et al. (2019) explained that lack of corporate leadership and project leadership, and software functionality issues are the barriers to BIM adoption in the Malaysian construction industry. In the Irish construction industry, McAuley and Carrol (2017) concluded that BIM adoption barriers for small and medium construction organisations entail lack of access to finance, lack of knowledge and skills, fear of low success in adopting technology, poor levels of communication and information exchange between parties in the construction process, and cultural change.

In Australia, Edinsinghe et al. (2016) established that inappropriate information in building information models, incompatibility between BIM and existing asset management systems, workflow disintegration, high cost of technology, lack of industry push, the low priority placed on BIM in property portfolio plans, and unawareness of correct requirements are the barriers to BIM adoption in facilities management practices. Gomez-Sanchez et al. (2016) reported that, in the Colombian construction industry, the BIM adoption barriers consist of lack of BIM knowledge, resistance to change, high cost of BIM adoption, and lack of BIM competent professionals. Bosch-Sijtsema et al. (2017) explored the perceived constraints of BIM adoption to small firms in Sweden. The study reported that team members not using BIM, lack of demand for BIM by clients, absence of internal demand in the small organisations, and negative evaluation of BIM are the barriers to BIM adoption by the small and medium construction organisations in Sweden.

The barriers to 5D BIM adoption by quantity surveying firms in New Zealand were reported by Harrison and Thurnell (2015) to include incomplete design, insufficient model object data in the building information model, lack of standards to facilitate electronic measurement, legal issues, and lack of government support. Likewise, numerous studies have suggested and conceptualized the BIM implementation strategies that will cause a reduction in BIM adoption barriers. For example, Olawumi et al. (2018) recommended the development of expertise, awareness and capacity development, and top management commitment as the strategies for overcoming barriers to BIM-enabled sustainability practices. Yang and Chou (2018) recommended the publication of a BIM implementation guide, provision of support to universities to provide BIM education, and hosting of BIM conferences as the BIM implementation strategies for overcoming BIM adoption barriers.

Liu et al. (2015) speculated on the appropriate driving forces from the government to promote BIM implementation. According to the study, improved national standards, BIM education and training, and mandatory BIM application will provide the required forces to guide and lead towards BIM adoption. Dainty et al. (2017) proposed financial motivations to use BIM, access to BIM hardware, software and services, BIM skill acquisition, and ease of BIM use as the strategies for driving BIM adoption among small firms. Mustaffa et al. (2017) identified the development of BIM standards as the initiative that is required and needed to ensure the success of BIM implementation globally. Abbasnejad et al. (2016) reviewed the key enablers for effective BIM adoption. The review led to the conclusion that strategic initiatives, change management, cultural readiness, learning orientation, knowledge capability, network relationships, and process management will be effective for a widespread BIM adoption.

Cao et al. (2017) contextualized the motivations for BIM adoption in China. The study concluded that the motives for BIM adoption for construction organisations are largely based on economic considerations. A notable study by Zhou and Yang (2019) identified the barriers to the on-going BIM implementation process in China. The study mapped the identified barriers to the contents of BIM implementation strategies. This led to the following propositions: what is needed are free intellectual property rights, assessment of BIM skills in the industry, encouraging BIM best practices, setting up scientific research incentives, development of appropriate BIM contract templates or supplemental contractual provisions for BIM adoption, provision of financial support for BIM implementation, and aggressive promotion of BIM cooperation and collaboration. The evidence provided by these studies suggests that BIM implementation strategies create provisions, such as the availability of BIM technologies, enactment of BIM-friendly legislation and policies, awareness and understanding of BIM concepts by professionals and clients, and availability of BIM competent professionals, which are fundamental to BIM implementation in any construction industry because they represent the foundation on which the BIM implementation efforts are built.

Further, the evidence in these past studies explains that BIM implementation can be said to be emerging in the construction industry when, in that construction industry, there are general BIM implementation efforts at the industry level and BIM adaptation efforts at the organisation level. This will create a stage of BIM implementation process that shows a reduction in the BIM barriers at both industry and organisation levels, such as the development of collaborative teamwork culture, acquisition of BIM infrastructure and technology, formulation of BIM adoption-based organisational vision, and BIM adoption-based organisation structures and culture. At this stage of the BIM implementation process, there are still barriers to BIM adoption because BIM adoption may not be widely practised on projects. The only difference is that the people, process, and technology required for BIM adoption in the organisation are available in the industry in which the organisations operate before they are personalized in the organisations or deployed on projects (Son et al., 2015). This is evident in the number of studies on BIM adoption on construction projects, which are not as many as the research on BIM adoption in the construction industry (Cao et al., 2015; Kerosuo et al., 2015).

Also, it is an indication that the state of reduction in BIM adoption barriers is an intermediate stage between the initiation of BIM implementation strategies and BIM adoption on construction projects. Specifically, the features of BIM implementation become available in a construction industry when the significant BIM adoption barriers are addressed through BIM implementation strategies (Succar and Kassem, 2016; Son et al., 2014). Based on this understanding, it can be concluded that BIM implementation is a process that requires that significant barriers to BIM adoption must be addressed gradually and systematically. It suggests that BIM implementation strategies must be applied to eliminating barriers to BIM adoption barriers on construction projects.

2.3.4 Relationship between reduction in BIM adoption barriers and level of BIM adoption on construction projects

The obstructive effect of BIM adoption barriers on BIM adoption is an indication of a relationship between them. BIM adoption barriers obstruct BIM adoption at the industry level, organisational level, and project level (Silva et al., 2016; Jin et al., 2015). This connotes that the barriers to BIM adoption manifest at the level of BIM implementation (BIM adoption in the construction industry), BIM adaptation (BIM adoption in construction organisations), and BIM utilization (BIM adoption on projects). This reality implies that there is a corresponding reduction in BIM adoption barriers with every progression in the level of BIM adoption. BIM adoption on construction projects is the ultimate adoption of BIM, and it will take a long process (Jin et al., 2015).

The large gap between BIM adoption in the construction industry and BIM adoption on construction projects denotes the process of reduction in BIM adoption barriers. Reduction in the barriers to BIM adoption at the industry level will bring a level of BIM adoption that will be signified by BIM adoption by all types of clients, development of discipline-specific roles and responsibilities in BIM adoption, adoption of BIM as a project delivery system, and alignment of project expectations with BIM potentials (Mostafa et al., 2020; Li et al., 2017; Latiffi et al., 2015). At the organisational level, reduction in the barriers to BIM adoption will cause the construction organisations to direct their visions, cultures, capacities, and investments towards the adaptation of BIM process and technology to their organisational work processes (Saka and Chan, 2020; Mostafa et al., 2020; Mehran, 2016; Khodeir and Nessim, 2018).

An efficient, vigorous and continuous BIM adoption on construction projects will be ushered in by a reduction in BIM adoption barriers at the project level (Zandieh et al., 2016; Liu et al., 2017). More than a few studies have investigated BIM adoption barriers that must be reduced or eliminated in different countries, different organisations, and different project types. For example, Zhou and Yang (2019) identified the barriers to the use of BIM implementation strategies in China to include insufficient government direction, legal issues, insufficient BIM motivations, and organisational issues. In Saudi Arabia, Al-Yami and Sanni-Anibire (2019) conducted a case study of a local architectural-engineering-and-construction firm. The study reported that lack of BIM policy, lack of sufficient BIM research, and resistance to change are the BIM adoption barriers that must be reduced.

Lack of software compatibility, prohibitive set-up costs, lack of protocols for coding objects within building information models, lack of an electronic standard for coding BIM software, and lack of integrated building information models were identified by Stanley and Thurnell (2014) as the BIM adoption barriers that must be reduced towards the implementation of 5D-BIM by quantity surveying firms in Auckland. Ma et al. (2019) identified corporate leadership, project leadership, and software functionality as the BIM adoption barriers that must be reduced in China. In India, Kushwaha and Adhikari (2016) reported that BIM adoption barriers that must be reduced include the hesitation to adopt new technology, lack of BIM experts, heavy initial cost, and lack of initiative and involvement from the government.

In the same way, numerous studies have been conducted on different forms or levels of BIM adoption on construction projects. For example, Lu and Lee (2017) explored the use of image-based technologies for constructing as-is-BIM for existing buildings. The study explained that to create as-is-BIM for an existing building, there is a need to collect existing documents and descriptions of the as-is-condition of the building. The study further proposed a framework of technologies and processes for constructing as-is-BIM. A semi-automatic methodology for generating semantic-rich structural building information models from 2D-computer-aided-design drawings was proposed by Yang et al. (2020). The study validated the feasibility of the methodology using two case studies of frame structures and concluded that the method is useful for quick and accurate authoring of the structural building information model with many elements that reflect the structural details described in the construction drawings.

The use of laser scan data was proposed by Wang et al. (2018) for automatic quantification of the dimensions of precast concrete bridge deck panels. Guo et al. (2020) presented a 3D terrestrial laser scanning approach for conducting time and cost analysis of the geometric quality assessment of structural columns. The approach was divided into manual data analysis and automatic data analysis. The time data were classified as fixed time and variable time, while the cost data were classified as project data and company data. It was concluded that the approach has the potential to ensure an economical and time-saving geometric quality assessment.

Zhang et al. (2016) demonstrated the use of BIM to support the modular design and industrialized construction in China. The study reported the use of BIM technology, such as 3D laser scanners and robotic total stations, to collect as-built data and establish a point cloud model for better mechanical-electrical-plumbing system coordination. The potentials of BIM in green building design through building performance analysis was explained by Chang and Hsieh (2020). According to their study, the potentials of BIM in green building design include energy and thermal analysis, green building rating analysis, cost and benefit analysis, wind and ventilation analysis, acoustic analysis, and water efficiency analysis.

The findings of these studies confirm that BIM adoption is a boundless advancement that is determined by the rate of reduction in the barriers to BIM adoption.

2.3.5 Relationship between the level of BIM adoption on construction projects and levels of integration and collaboration among the BIM-SCM

Integration and collaboration, such as trust-based relationships, improved communication, improved coordination, shared interests, mutual commitment, and collective decision-making, manifest among the project participants as a result of the efficiency and effectiveness of project delivery tools, technologies, processes and systems such as BIM (Ozorhon and Karahan, 2016; Won and Lee, 2016; Rahman et al., 2016; Hagiagha et al., 2016; Prostejovska and Tomankova, 2017; Tsiga et al., 2016; Berssaneti and Carvalho, 2015; Williams, 2016; Cheong and Mustaffa, 2017; Babu and Sudhakar, 2015). Researchers, such as Papadonikolaki et al. (2015) and Fazli et al. (2014), have argued that BIM provides efficient integration and collaboration tools and platforms for construction management by allowing the project team members to work collaboratively, allowing the project managers to coordinate the project delivery process effectively, and allowing the project information to be well communicated, exchanged and integrated.

Other studies have provided evidence in support of a positive relationship between BIM adoption on construction projects and collaboration among the BIM-SCM in the form of case studies. For instance, Bensalah et al. (2019) investigated the adoption of BIM for railway design and construction. The study identified time saving, collaboration opportunities, cost optimisation, prevention of conflicts, visualization, effective maintenance, opportunities for prefabrication, and improved quality as the benefits of BIM integration in railway design and construction. Andujar-Montoya et al. (2020) conducted a case study of BIM-LEAN as a methodology for saving execution costs in building construction. A public construction project at the University of Alicante was used as the case study. The study made a comparison with the project data in relation to cost deviations of other similar public projects, which were delivered using a non-BIM methodology.

Ciribini et al. (2016) reported a case study of a residential building on which BIM tools and processes were applied. As reported by the study, the traditional procurement system was used on the project and a form of collaboration took place among the project participants, which optimized the design process and improved project coordination through semi-automatic quantifications and 4D scheduling. Also, Czmuch and Pekala (2014) reported a case study of an office complex involving ten professionals. The study reported coordination benefits such as elimination of errors and clashes in information, fewer requests for information, and fewer changes, accurate ordering of materials, and improved qualities of materials.

Frameworks developed by various studies on BIM adoption have also illustrated the usefulness of BIM tools, principles, and processes in generating integrations and collaborations among the BIM-SCM. For example, Cortes-Perez et al. (2020) proposed the methodology for integrating BIM in the management of occupational hazards in building construction and maintenance. The methodology is useful for integrating health and safety regulations into project design and planning. Elghaish et al. (2020) developed a framework for integrating BIM with blockchain technology to create an automated financial system. The study claimed the framework will enable the BIM-SCM to automatically execute financial transactions as functions of integrated project delivery smart contracts. To facilitate the adoption of the framework, an integrated project delivery case project was used to demonstrate the framework. The study concludes that the framework is user-friendly and efficient in automating financial transactions.

Kalfa (2018) discussed and investigated the use of BIM as a new project management approach for construction projects in Turkey. Junior et al. (2020) developed a framework for BIM adoption as a project management approach in public organisations. The framework identified three areas where BIM-enabled project management can be applied in public project administration. These include project development procedures, model development procedures, and public governance policies. Palomar et al. (2020) created an online work platform for BIM adoption in heritage architecture. The study designed an innovative in-cloud system that connects the intrinsic heritage BIM database with heritage documentary databases. The study asserted that the platform will allow non-technical heritage stakeholders to effectively collaborate on heritage architecture. Alonso et al. (2020) assessed the possibility of a highly interactive collaborative nD-BIM digital twin platform of building design and construction together with manufacturing and operational phases. The study argued that the system will be capable of aggregating all data relevant to the asset through all the lifecycle phases of the residential building, hence improving productivity through time-efficiency, economic decision-making, and environmental decision-making.

The scope and findings of these past studies suggest that level of BIM adoption on construction projects moderates the level of integration and collaboration among the BIM-SCM. According to Tan et al. (2017), Ding et al. (2014), Lu et al. (2016), and Oraee et al. (2017), the level of effectiveness or level of BIM impact relates to the amount of project information to be integrated and the number of project team members to collaborate and relate as the core of the project team, the level of BIM competence and experience of the project team members, level of development of information, the extent of collaboration between the project team members, and extent of integration of project information. Rokooei (2015) concurred that for less complex projects, less complex integration of project information, and a non-extensive collaboration of project participants are required so as to save time and money. This signifies that the impact of BIM on a construction project is dependent on the extent of BIM adoption on the project. It also signifies that BIM has different levels of effectiveness depending on the extent of BIM adoption, and the extent of BIM adoption on a project determines the levels of integration and collaboration among the BIM-SCM (Ozorhon and Karahan, 2016; Tan et al., 2017; Zandieh et al., 2016; Tulenheimo, 2015).

The significance of the relationship between the level of BIM adoption on construction projects and the levels of integration and collaboration among the BIM-SCM is that it moderates the BIM performance and benefits. This means that the levels of integration and collaboration that will be achieved increase with the level of BIM adoption on a project. The moderation effect of the level of BIM adoption on construction projects on the levels of integration and collaboration among the BIM-SCM, as a result of their relationship, is reflected in terms of the integration of the design and construction team. It is also reflected in terms of the creation of building information models, enablement of greater understanding of project complexity and cost, and lack of adversarial behaviour between the BIM-SCM. Also, BIM adoption on construction projects offers a climate where collaborative culture can be nurtured over a number of projects because it allows the project participants to have some measure of collaboration by enabling trust development, common goals, commitment, teamwork, shared risk, open communication, good working relationships, and a win-win philosophy.

2.4 Summary of literature review

This chapter presents an overview of past studies on BIM implementation and adoption. The chapter reveals that previous studies have almost exclusively concentrated on the possibilities of BIM adoption for the various aspects of project delivery. This was evident in the number of BIM adoption frameworks that were proposed by scholars and it is an indication of a lack of deep understanding of the levels of BIM adoption on construction projects. It also indicates a lack of extensive case studies of actual and practical BIM adoption on construction projects.

Also, the chapter explains that the concept of BIM-enabled integration and collaboration has been assessed only to a very limited extent and that the existing research on BIM-enabled integration and collaboration has many shortcomings. This emphasises the need to investigate the concepts of integration and collaboration as a BIM process and provide empirical evidence for the occurrence of integration and collaboration among the BIM supply chain members.

The chapter also theorized on the relationship between BIM adoption and BIM implementation strategies, the relationship between the level of BIM adoption on construction projects and the levels of integration and collaboration among the BIM supply chain members, and the relationship between the level of BIM adoption and rate of reduction in the barriers to BIM adoption.

CHAPTER THREE

THEORETICAL AND CONCEPTUAL FRAMEWORK

3.1 Introduction

This chapter provides the rationale for conducting this research. It presents information on the theoretical insights, theoretical framework, conceptual framework, and conceptual background that were employed in this research.

3.2 Theoretical framework

3.2.1 Theories and theoretical insights

Theories are postulations or established hypotheses that explain, define, suggest variables, and specify relationships among the key variables (constructs) towards informing the understanding of a phenomenon or a research problem (Sutton and Staw, 1995; Casanave and Li, 2015; Sefotho, 2015). The existing postulations and theories on a research problem provide the conceptual basis for defining, identifying, investigating, and understanding the research problem (Osanloo and Grant, 2016; Lynham, 2002; Tavallaei and Talib, 2010). Also, they provide the means for solving research problems, giving meaning to research findings, identifying critical research questions, developing theoretical or conceptual models, and grounding research works in existing and established knowledge (Ravitch and Carl, 2019; Repko and Szostak, 2020; Hennink et al., 2020; Trochim, 2006). This means that the theoretical insights and framework for research are derived from the existing theories and postulations.

According to Embrey (2020) and Lana (2019), theoretical insights are the understanding provided by the explanations, predictions, and perspectives offered by the existing postulations and theories on a phenomenon. Blanco Pérez (2020) and Ravitch and Carl (2019) describe a theoretical framework as the structure offered by, or deduced from, existing postulations or theories. Theoretical insights provide an understanding of the contextual components of a phenomenon (Nilsen, 2020), and represent the assumptions or principles that are developed through the explanatory power of the existing postulations and theories (Jaccard and Jacoby, 2019). On the other hand, a theoretical framework is a clear way of defining and explaining the existing postulations and theories that underlie research (VanPatten et al., 2020). Specifically, the theoretical framework illustrates the concepts, explanations, and understanding offered by theories, and also connects the current research to the existing literature on the research problem (Ghauri et al., 2020). Andersson et al. (2020) and Ary et al. (2018) noted that a theoretical framework enables the identification of the key variables in the research problem, enables the determination of the research expectations and contributions, and facilitates the identification of relationships among the key variables. However, there is no one perfect or single theory that could correctly and adequately explain a phenomenon that requires insights from a range of dimensions (Bloomberg and Volpe, 2018).

3.2.1 Theoretical pluralism and Implementation process theory

It is argued by Midgley (2011) and Bernardi (2018) that theoretical pluralism (a combination of theories) will lead to theoretical insights that would be impossible to come about as a result of the use of a single theoretical perspective. Likewise, Nielsen (2020) noted that related theoretical insights from multiple theories must be combined in research that would contribute meaningfully to knowledge and theories on a phenomenon. Christensen et al. (2020) maintained that the study of a complex and new phenomenon requires theoretical pluralism because of the need for a different perspective. According to Sydow and Braun (2018), non-conflicting concepts, postulations, and relationships from several theories are impactful for leading-edge research. Therefore, theoretical pluralism is essential to grasp the concept of BIM implementation as a complex and new phenomenon.

As reported by Pouliot et al. (2018), Ahuja et al. (2020), and Kepczynska-Walczak (2018), BIM implementation is a complex and multi-dimensional phenomenon that combines BIM (with facets such as innovative technologies and processes, management system, and project delivery system) and implementation (with facets such as adoption, adaptation, and application process). Thus, this research draws from the theoretical perspectives of the Implementation Process Theory (IPT). IPT postulates on the process of initiating and sustaining adoption decision by individuals and organisations that operate in an industry (Yetton et al., 1999; Al-Mashari and Zain, 1999; Jackson, 1997; Proctor et al., 2013; Nilsen, 2020; Damschroder, 2020; Mabert et al., 2003; Meyers et al., 2012). The theory explains that the adoption decision in an organisation will experience tensions, resistance, strains, and conflicts; and that a critical assessment of these barriers is required to avoid implementation failures (Smith, 1973; Al-Mashari and Zain, 1999). Further, the theory advances that it is natural for the members of an organisation to resist change, but the members will fall in line with the change if prompted by the top management (Yetton et al., 1999). This suggests that the implementation process is influenced by the commitments of the organisations' top management and cover the organisational and managerial resources to be expended to meet the implementation process and strategy requirements.

Equally, Klein and Knight (2005) pointed out that individuals and organisations that operate in the industry must possess the skills, competence, and training that are consistent with innovation or new practice to achieve a successful and sustained implementation of the innovation or practice. Khalfan et al. (2015) posited that the adoption of an innovation or a practice in an organisation depends on the commitment, structure, and culture that will be established by the top management of the organisation towards the continued use of the innovation or the continuity of the practice. This means that the commitment of organisations' top management is essential to managing the transition, resistance, competency, organisational structure, and resources, as well as promoting collaborative teamwork culture in their organisations in the course of the implementation process (Al-Mashari and Zain, 1999; Mumford, 1995).

Similarly, studies on BIM adoption have shown that BIM adoption in organisations requires hefty investments of time and money in technology, training, and structural change (Wong and Yew, 2017; Ghaffarianhoseini et al., 2017; Li et al., 2019). The implication of this is that BIM implementation process will not be successful and sustainable without putting in place measures that will bring about motivations for BIM adoption (Ding et al., 2015; Cao et al., 2017), BIM-enabled competitive edge for organisations (Rogers et al., 2015; Tulubas Gokuc and Arditi, 2017; Ahn et al., 2016), and efficiency and effectiveness in the application of BIM on construction projects (Tulenheimo, 2015; Doumbouya et al., 2016). Also, Cao et al., (2017) and Zhu and Mostafavi (2017) explained that BIM implementation is a complex process and the justification for, and the effectiveness of, BIM implementation strategies depend on their capabilities in addressing a wide range of issues, such as utilization strategies for BIM based on the characteristics of construction project supply chain players and construction projects, human capacity challenge, commitment and support of organisations' top management, and motivation for adoption decisions.

The perspectives from IPT were modified with the existing postulations on BIM adoption requirements and challenges to facilitate the understanding of the concepts and variables associated with ensuring a successful and sustained BIM implementation. IPT has a limitation because it is an interdisciplinary theoretical perspective; hence, the need to modify it with BIM-related postulations to complement its strengths and deficiencies. It is expected that this will provide adequate insights into the complexity of BIM adoption and implementation. This research displays strong heterogeneity in terms of theoretical perspectives, thereby reflecting the multi-faceted nature of BIM implementation. IPT modified with BIM-related postulations gives a theoretical insight that explains BIM implementation as a process which requires (a) two types of BIM adoption, namely, preliminary BIM adoption and sustained BIM adoption, (b) identification of barriers to preliminary BIM adoption, (c) identification of barriers to sustained BIM adoption, (d) development of strategies to overcome the barriers and drive BIM adoption on projects, and (e) the management of BIM adoption to achieve the benefits of BIM adoption on projects (that is, integration and collaboration among the BIM supply chain members). Figure 3.1 summarizes the BIM implementation process based on the modified IPT.

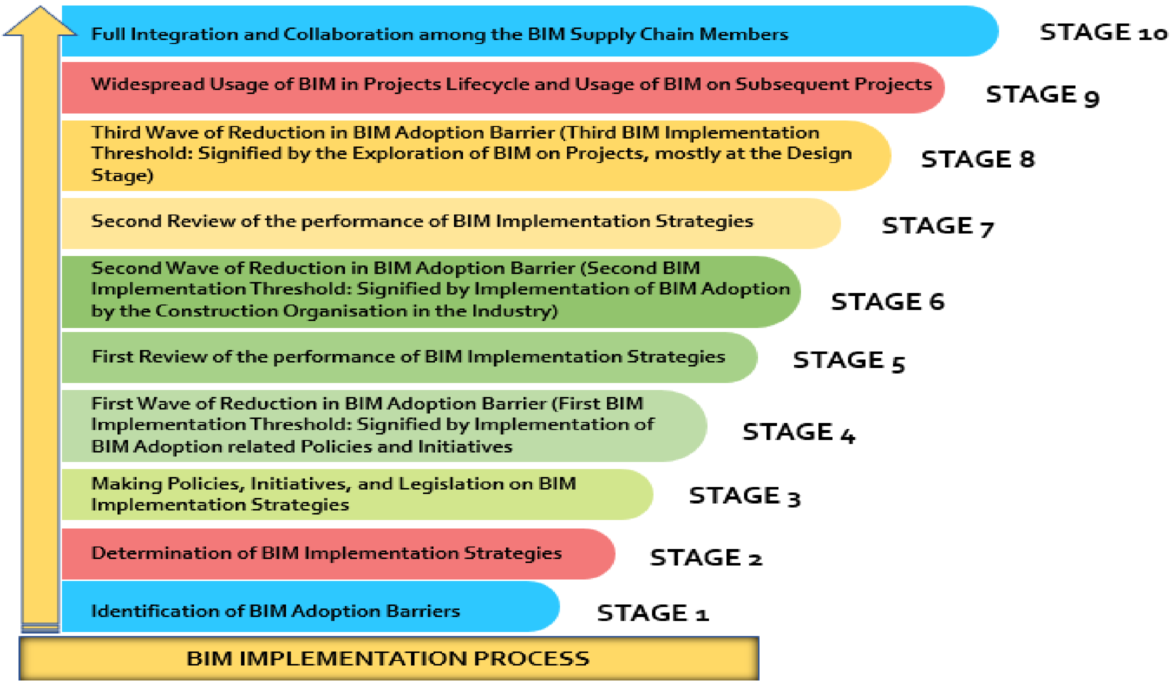

Figure 3.1: BIM implementation process

Also, the insights from the modified IPT highlights the importance of the following dimensions to the success and sustainability of BIM implementation in the construction industry: commitment, motivation, culture, education and training, skills and competence, competitiveness, efficiency, and effectiveness. The theoretical perspectives from modified IPT are summarized in Figure 3.2. The theoretical perspective indicates the need for different strategies to initiate the BIM implementation process. These strategies include *BIM* *motivations*, *BIM commitments*, *BIM capacity development*, and *BIM utilisation*; all collectively described as "*BIM implementation strategies*" in this research. Based on these theoretical perspectives, this research proposed a theoretical framework for a successful and sustained BIM implementation (see Figure 3.2). The theoretical framework was developed in this research because of the need to collect quantitative data for validating the theoretical insights provided by the modified IPT. The framework was developed by illustrating the key stages of a successful BIM implementation based on the insights provided by the modified IPT. The stages were broken into the required forces for driving BIM implementation and objectives of a successful BIM implementation. The forces were linked with the objectives to indicate their effects on the barriers to BIM adoption. These effects were identified to include reduction in barriers to BIM adoption, widespread BIM adoption, and realisation of the benefits of BIM adoption.

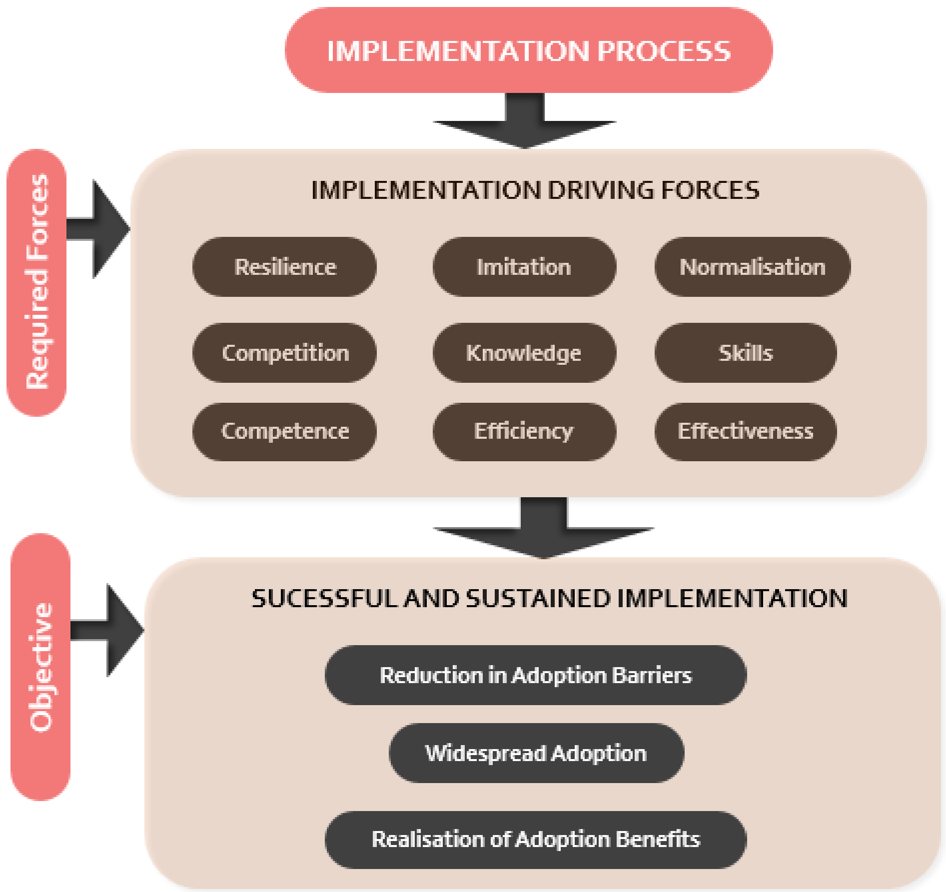

Figure 3.2: Theoretical framework for a successful and sustained BIM implementation

3.3 Developing the theoretical model

A theoretical model is a descriptive representation of the theoretical framework that explains the key concepts in the research in a narrative form (Christensen et al., 2020; Ravitch and Riggan, 2016; Bingwen, 2019; Jarvis, 1999; Torraco, 1997). The theoretical model for this research is presented in Figure 3.3. The theoretical model for successful BIM implementation is related to the theoretical framework for a successful BIM implementation because it provides a descriptive representation and explanation of the key concepts in the theoretical framework. While the theoretical framework merely listed the procedures for a successful BIM implementation, the theoretical model explains the details of the stages in the BIM implementation process. The explanations and descriptions provided by the theoretical model are required to set up the foundation for the conceptual model, guide the formulation of hypotheses, and guide the identification of hypothesized relationships.

The theoretical model was developed by analysisng the driving forces for BIM implementation to conceptualise the BIM implementation strategies that suit the objectives of each of the driving forces. Constructs were formulated to organise the strategies and link the strategies to the objectives of a successful BIM implementation. The constructs (BIM commitments, BIM motivations, BIM capacity development, and BIM utilisation) were positioned to connect the objectives of the driving forces with those of a successful BIM implementation.

It was developed to describe the BIM implementation process and the benefits that were identified in the theoretical framework. It describes the BIM implementation scenario through an interactive process whereby the driving forces from BIM implementation strategies bring about a significant reduction in BIM adoption barriers, widespread adoption of BIM on projects, as well as integration and collaboration among the BIM-supply chain members. The result of the process, as illustrated in the theoretical model (see Figure 3.3) is a successful and sustained BIM implementation. The theoretical model facilitates the understanding of the concepts and variables associated with a successful and sustained BIM implementation as identified in the theoretical framework.

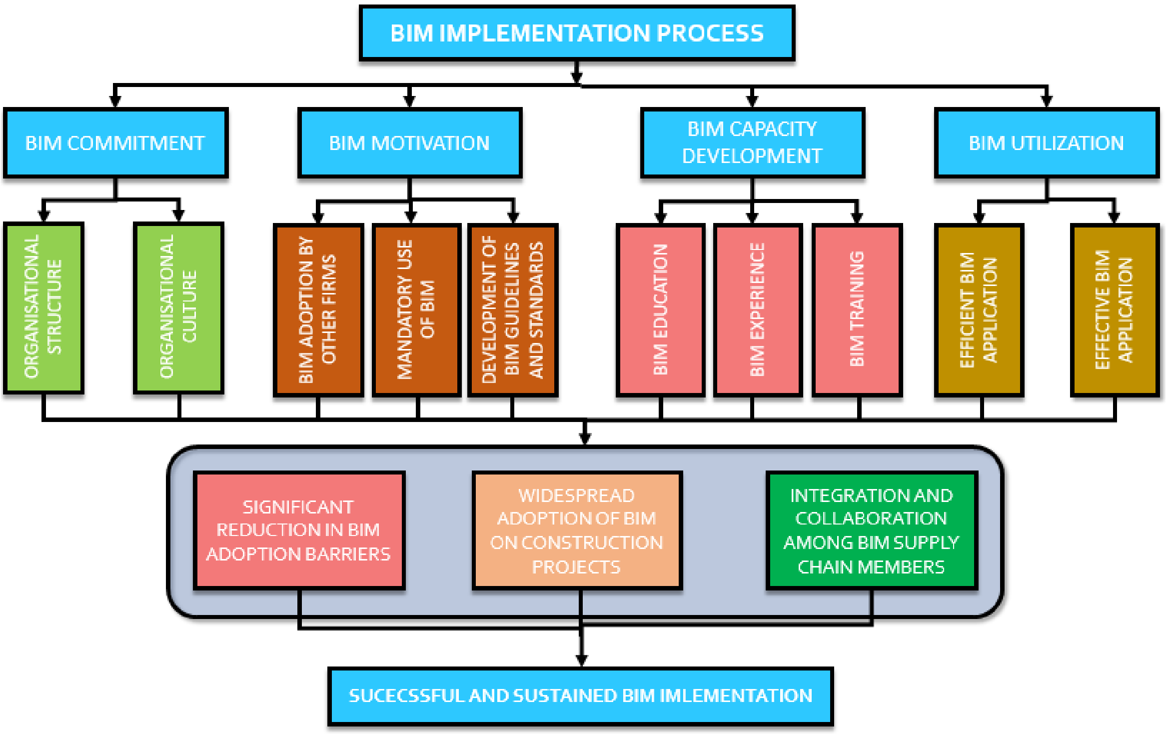

Figure 3.3: Theoretical model of a successful and sustained BIM implementation

To ensure a successful and sustained BIM implementation, the driving forces from BIM implementation strategies must be comprehensive or multi-dimensional and must address the market, socio-cultural, technical and legal interplay in the construction industry (Miettinen and Paavola, 2014; Cao et al., 2015; Zhu and Mostafari, 2017; Cao et al., 2017). These characteristics become necessary because of the need to drive BIM adoption at the industry, organisation, and project level; and the need to cater to the economic viability of small and medium construction organisations (Miettinen and Paavola, 2014; Bui et al., 2016). Also, ensuring a successful and sustained BIM implementation in the construction industry means that both public and private clients must demand BIM, the benefits of BIM adoption must be aligned with the industry and project needs (to ensure effective and efficient BIM application on projects by relating the level of BIM application to the types, sizes, and expectations of projects), BIM guidelines and standards must be developed, BIM education and training must be prioritized, and construction organisations must respond to the BIM-related competition and marketing opportunities (Ayman et al., 2020; Kensek, 2015; Di Giuda et al., 2020; Lee et al., 2020).

Observations from the prevailing BIM implementation efforts indicate that BIM implementation becomes impactful at the project level and that organisations, professionals, and clients must be motivated to adopt BIM. These suggest that, to overcome the complexity of BIM implementation and BIM adoption decisions, the BIM capacity of the present and future construction professionals must be developed, BIM application on projects must be effective and efficient, and the cooperation of top management of construction organisations towards BIM adoption must be secured (Shirowzhan et al., 2020; Abdulaal et al., 2017; ElGewely et al., 2020; Siebelink et al., 2020; Ma et al., 2020). This reality informs the theoretical model for this research as shown in Figure 3.3.

3.4 Developing the conceptual model

A conceptual model is a visual representation of the paths in the theoretical model (Greca and Moreira, 2000; Franco et al., 1999; Guarino et al., 2020; Delcambre et al., 2019). In this research, the theoretical model that was developed from the theoretical insights and frameworks provided by the modified IPT (see Figure 3.3 and theoretical background in Chapter Two) was conceptualized into a conceptual model (see Figure 3.4). The conceptualisation was done by identifying the elements that determine the BIM implementation process. These elements (BIM implementation strategies, reduction of barriers to BIM adoption, levels of BIM adoption on projects, and levels of integration and collaboration among the BIM supply chain) were taken as the constructs to be used in this research. The relationships between the constructs were determined by identifying the interactions in the theoretical model. The hypothesisied relationships in the conceptual model were formed by linking the constructs together in line with the established relationships in the theoretical model.

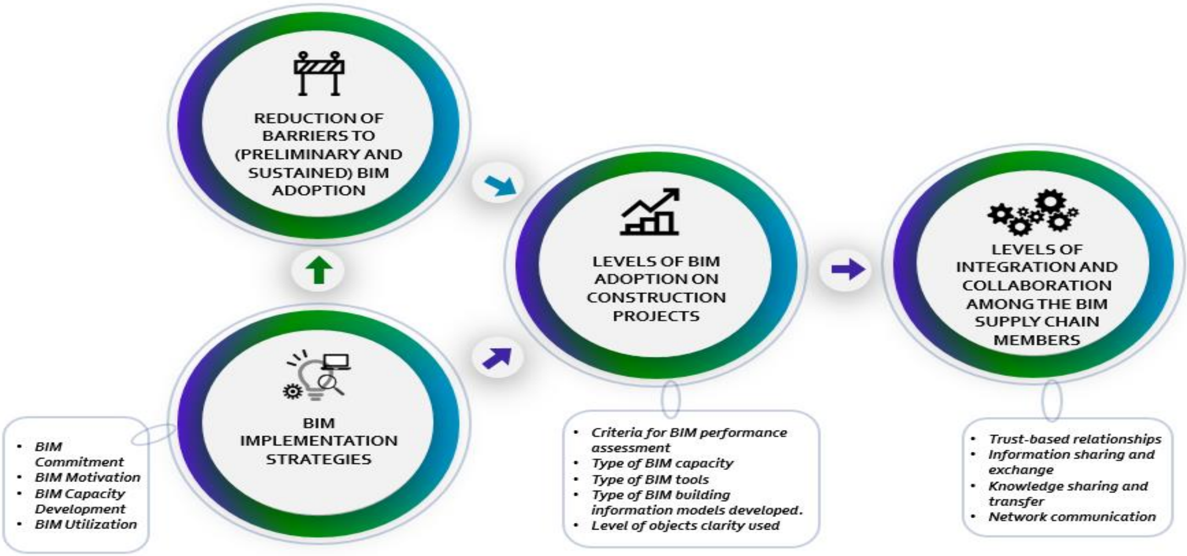

Figure 3.4: Conceptual model for the research

As shown in Figure 3.4, the conceptual model for this research combines the key concepts and constructs that were used in this research and provides the structures for the theoretical background for the research (Roussopoulos and Karagiannis, 2009). It was developed to serve as the graphical illustration of the concepts that were investigated in this research and the hypothesized relationships among them, as well as to serve as the point of reference for this research. According to Parush (2015) and Robinson et al. (2015), the conceptual model shows the link between the research hypothesis and the literature review, emphasizes the predictions of the theoretical model, enables the understanding of the theoretical underpinning of the research, and enhances the understanding of the theoretical model.

The conceptual model for this research features the interactions between the stages in the BIM implementation process (that is, the launch of BIM implementation strategies, the occurrence of reduction in barriers to preliminary and sustained BIM adoption, the occurrence of widespread BIM adoption on construction projects, and occurrence of integration and collaboration among the BIM supply chain members). The structural equations that were generated to describe the hypothesized relationships in the conceptual model and to guide the model estimation are explained in *Equation 3.1 – Equation 3.5*). The notations for the structural equations are presented in Table 1.

RELATIONSHIPS	***STRUCTURAL EQUATIONS***	
$Y \rightarrow K$:	$K = \beta_0 + \beta_1 Y + e$	***Equation 3.1***
$Y \rightarrow M$:	$M = \beta_0 + \beta_2 Y + e$	***Equation 3.2***
$Y + M \rightarrow K$:	$K = \beta_0 + \beta_3 M + \beta_4 Y + e$	***Equation 3.3***
$K \rightarrow Z$:	$Z = \beta_0 + \beta_5 K + e$	***Equation 3.4***
$M \rightarrow K$:	$K = \beta_0 + \beta_6 M + e$	***Equation 3.5***

$where\ Y = (Y_1 + Y_2 + Y_3 + Y_4),$
$K = (K_1 + K_2 + K_3 + K_4 + K_5), and\ Z = (Z_1 + Z_2 + Z_3 + Z_4).$

Table 3.1: Notation for the conceptual model and structural equations

Variable	**Description**
Z	*Levels of integration and collaboration among the BIM supply chain members*
Y	*BIM implementation strategies* as measured by (Y_1 = *BIM Motivation*), (Y_2 = *BIM Commitment*) , (Y_3 = *BIM capacity development*), (Y_4 = *BIM utilization*)
M	*Reduction in the barriers to preliminary and sustained BIM adoption*
K	*Level of BIM adoption on construction projects* as measured by (K_1= *Criteria for BIM performance assessment*), (K_2 = *Type of BIM capacity*), (K_3 = *Type of BIM tools*), (K_4 = *Type of building information models (bim) developed*), (K_5 = *Level of objects' clarity*)
β_0	The intercepts for Equation 1 to Equation 5
$\beta_2 – \beta_6$	The corresponding structural coefficients in Equation 1 to Equation 5
e	The corresponding residuals in Equation 1 to Equation 5

The conceptual model was designed as a mediated model to explain an efficient BIM implementation process where BIM implementation strategies (*Y*) is the *causal variable,* reduction in the barriers to preliminary and sustained BIM adoption (*M*) is the *process variable* or *intervening variable,* level of BIM adoption on construction projects (*K*) represents the *outcome*, while levels of integration and collaboration among the BIM supply chain members (*Z*) represents the *resulting variable* from the *outcome.* The *causal variable* (*Y*) comprises four sub-constructs namely: BIM commitment (*Y1*), BIM motivation (*Y2*), BIM capacity development (*Y3*), and BIM utilization (*Y4*). As a mediated model, the model explains that the *causal variable* (*Y*) has a direct effect on the *outcome* (*K*) and the *intervening variable* (*M*). Also, the *intervening variable* (*M*) has a direct effect on the *outcome* (*K*); while the *outcome* (*K*) has a direct effect on the *resulting variable* (*Z*). The conceptual model collapses the total effect of the *causal variable* (*Y*) on the *resulting variable* (*Z*) into 3 parts: the direct effect of the *causal variable* (*Y*) on the *intervening variable* (*M*); the direct effect of the *causal variable* (*Y*) on the *outcome* (*K*); and the direct effect of the *outcome* (*K*) on the *resulting variable* (*Z*).

The direct effect of the *causal variable* (*Y*) on the *intervening variable* (*M*) indicates that the *causal variable* (*Y*) will ensure a reduction in the barriers to preliminary and sustained BIM adoption on account of the four sub-constructs (*YI*, *Y2*, *Y3*, and *Y4*) of the *causal variable* (*Y*). The direct effect of the *causal variable* (*Y*) on the *outcome* (*K*) will ensure a sustained and strategic adoption of BIM on construction projects. The direct effect of the *outcome* (*K*) on the *resulting variable* (*Z*) will overcome the instability, fragmentation, ineffective documentation and coordination, distrust, and haphazard flow of information in project delivery.

3.5 Developing the hypothesized model

As a result of the conceptual model, this research theorizes the relationships between the key variables as well as hypothesizes the factors for a successful and sustained BIM implementation. This becomes important owing to the need for the development of broad themes, theories, and a generalized model of BIM implementation. The hypothesized relationships in the conceptual model include the correlation between the *causal variable* (*Y*) and the *outcome* (*K*), the correlation between the *causal variable* (*Y*) and the *intervening* *variable* (M), the correlation between the *outcome* (*K*) and the *resulting variable* (*Z*), the relationship between the *causal variable* (*Y*) and the *outcome* (*K*) as mediated by the *intervening variable* (*M*), and the effect of the *intervening variable* (*M*) on the *outcome* (*K*).

A diagrammatical design of the hypothesized relationships (interrelationships between the variables) in the conceptual model was developed as presented in Figure 3.5.

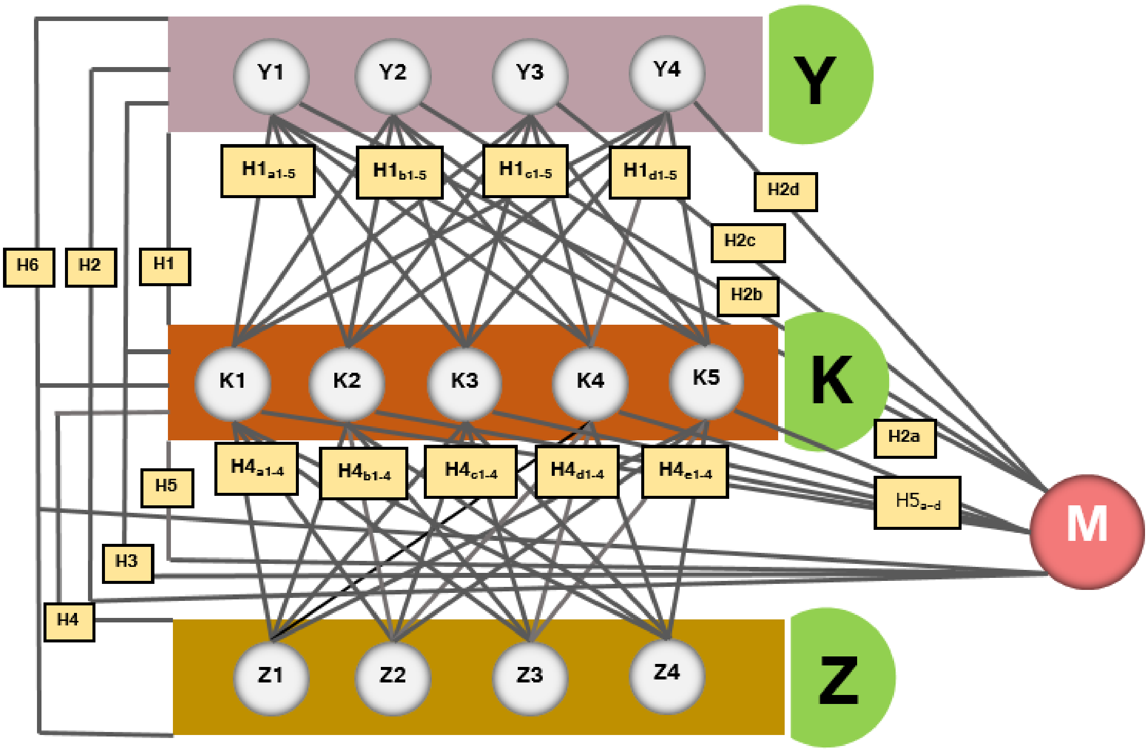

Figure 3.5: Hypothesised model for the research

These hypothesized relationships that are required to achieve objective 5 are stated as follows:

H1: *There is a significant positive relationship between BIM implementation strategies and level of BIM adoption on construction projects.*

H2: *There is a significant inverse relationship between BIM implementation strategies and barriers to preliminary and sustained BIM adoption on construction projects.*

H3: *Reduction in barriers to adoption mediates the relationship between implementation strategies and the level of BIM adoption on construction projects.*

H4: *There is a significant positive relationship between the level of BIM adoption on construction projects and the levels of integration and collaboration among the BIM supply chain members.*

H5: *A reduction in barriers to preliminary and sustained BIM adoption has a positive and significant impact on the level of BIM adoption on construction projects (that is, as the rate* *of reduction of barriers to preliminary and sustained BIM adoption increases, the extent of BIM adoption on construction projects increases)*

H6: *There is a significant positive interaction between the levels of integration and collaboration among the BIM-SCM, level of BIM adoption on construction projects, reduction in the barriers to preliminary and sustained BIM adoption, and BIM implementation strategies*

H6a: *There is a significant positive interaction between the levels of integration and collaboration among the BIM-SCM, level of BIM adoption on construction projects, reduction in the barriers to preliminary and sustained BIM adoption, and BIM implementation strategies in use*

H6b: *There is a significant positive interaction between the levels of integration and collaboration among the BIM-SCM, level of BIM adoption on construction projects, reduction in the barriers to preliminary and sustained BIM adoption, and BIM implementation strategies that are essential to the success of BIM implementation process*

3.6 Conceptual background

This section presents the key concepts that underlie the conceptual model for this research as illustrated in Figure 3.4.

3.6.1 BIM implementation strategies

Putting BIM adoption into practice successfully and sustainably in the industry requires plans, policies, and approaches that will create a change in organisational structure and culture of construction organisations towards adopting and adapting BIM to their organisational work process; create an enabling environment and impetus for BIM adoption in the industry; create the capabilities that are required to function in a BIM environment or to participate effectively in a BIM-based construction project; and establish an efficient and effective application of BIM on construction projects (Ahuja et al., 2020; Lu et al., 2018; Junior et al., 2020; Bakogiannis et al., 2020). This research conceptualized these plans, policies, and approaches as strategies for *BIM motivations, BIM commitments, BIM capacity development,* and *BIM utilization*.

3.6.1.1 BIM motivations

Motivation as a concept may manifest as intrinsic forces (desires or pleasure), personal challenge, external forces (regulations), desire for accomplishment, desire for value, the pursuit of excellence or achievement or competence, emotional kick to a move by the opposition, and desire for a positive effect (Shiroma, 2014; Shane et al., 2003; Benabou and

Tirole, 2003). The above manifestations of the concept of motivation indicate that there are set techniques that could be employed for creating internal and external drive, impetus and inspirations, desire and direction, needs and expectations, pleasure and satisfaction, and inducement and incentives for BIM adoption. In this research, these sets of techniques are conceptualized as BIM motivations. Therefore, BIM motivations describe the initiatives that create normative, imitative, and coercive forces for the purpose of creating reasons and inducements for BIM adoption. Also, this research posited that BIM motivations consist of normative, imitative, and coercive forces that are used for the purpose of creating reasons and inducements for BIM adoption. As explained by Bakogiannis et al. (2020) and Lindblad and Guerrero (2020), coercive forces will compel individuals, groups, and organisations to act in line with the expectations spelt out in guidelines and regulations. This means that normative forces will cause the industry actors to strive for identity, survival, and legitimacy in the industry.

Imitative forces will cause small construction organisations to follow the examples of large construction organisations. Collectively, normative force, imitative force, and coercive force may be referred to as motivating forces. This is acknowledged by Cao et al. (2017), who emphasized that the motivating forces for BIM adoption entail incentives, legislation, inducement, provocation, rationale, and inspiration. Likewise, Oo (2014) explained that the mandatory requirements of BIM in the contractor selection process and application for building permit is a motivating force in the form of legislation. In addition, Oo (2014) posited that BIM adoption by the rival firm is a motivating force in the form of provocation. The argument by Cao et al. (2017) suggests that these motivating forces will arouse interest in, and give reasons for, BIM adoption in the construction industry. This argument was further supported by Juan et al. (2017), who described the motivating forces for BIM adoption as the driving forces for increasing the readiness, enthusiasm, and willingness of a construction organisation or construction professional to adopt BIM. Therefore, it becomes clear that BIM motivations consist of the motivating forces that serve as the drive and reasons for the BIM adoption decisions.

The features of BIM motivations buttress the argument for it as a significant BIM implementation strategy. According to Cao et al. (2017), BIM motivation is essential for identifying BIM adoption goals, determining priorities, and drawing up a decisive and effective BIM adoption plan, overcoming BIM adoption barriers, and staying the course of BIM adoption. This means that BIM motivations will help create a good impression and corporate image about BIM adoption in an organisation. It will also substantiate and justify the need for BIM adoption on construction projects. BIM motivations will help stimulate the overcoming of BIM adoption barriers by ensuring the support and cooperation of the stakeholders with BIM implementation policies, creating desires in the construction professionals for a change in the work process, and creating pressure and interest among construction organisations for BIM adoption.

In terms of BIM implementation requirements, BIM motivation will empower the industry players to effectively pull their weight and achieve their maximum potential. Initiating BIM adoption is not as important as staying the course of BIM adoption. Thus, BIM motivations become important because they will create a sense of responsibility for BIM adoption, facilitate the self-development of construction professionals in terms of BIM competence, ensure that construction organisations and professionals put their best efforts towards BIM adoption, and enable construction organisations and professionals to be adaptive and receptive towards BIM adoption. More importantly, BIM motivations will encourage construction organisations to gracefully bear the financial implications of BIM adoption. More also, BIM motivation will develop a positive attitude and appreciation for BIM adoption and will help to smooth the BIM implementation process by ensuring that all the industry players make a maximum contribution.

In support of the significance of BIM motivations as a strategy for driving BIM implementation process, Papadonikolaki (2018) affirmed that BIM motivations, such as market and client demand for BIM will create the external and internal pressure that are required to motivate construction organisations and professionals to adopt BIM. It is a fact that most construction organisations and professionals lack BIM competencies and skills, which are essential to BIM implementation. However, BIM motivations create the willingness to acquire the required competencies, skills, and resources towards BIM adoption. This further emphasizes the importance of BIM motivations as an important strategy for driving the BIM implementation process. Although, it is essential to continually introduce innovative and new methods and processes in a dynamic business environment such as the construction industry. This is the case with BIM, as it has become a new and innovative way of working in the construction industry. However, the smooth and enthusiastic acceptance of BIM in the construction industry requires BIM motivations. The lack of BIM motivations in a BIM implementation process in the construction industry will cause resistance to BIM implementation. This is because construction organisations and professionals are driven by a multitude of different motives.

3.6.1.2 BIM commitments

Commitment is the sense of being bound emotionally or intellectually to some course of action (Naotunna and Arachchige, 2016). As a concept, commitment can take different forms, such as *work commitment*, *employee commitment*, *organisational commitment*, and *top management commitment*. *Organisational commitment* is a broad concept because it is both attitudinal and behavioural. In terms of attitudinal approach, commitment refers to a positive attitude about an organisation in terms of the perception of the organisation, personal characteristics, and work experiences (Cohen, 2014; Van Dyk and Coetzee, 2012). In terms of behavioral approach, commitment refers to behaviors that make it costly to subsequently reverse a position or disengage from a decision or an obligation (Peccei et al., 2011; Sahi and Mahajan, 2014).

Another broad concept of commitment is *top management commitment*. Commitments are offered by the top management in anticipation of future rewards or a change (Colwell and Joshi, 2013). Change is constant and the certainty of change affects the survival and competitiveness of organisations (Lines, 2004). The chance of survival and the extent of competitiveness of organisations depend on the top management's commitment to change. This means that top management commitment can be described as the willingness of the leadership of an organisation to persist and sustain a course of action or an obligation. In the context of top management commitment, the elements of commitment will, therefore, include the extent of investments, degree of obligations, a sense of pledge, a sense of responsibility, and a desire to preserve an obligation. According to Herscovitch and Meyer (2002), the elements of commitment can be used to predict the top management commitment for a course of action. Also, the elements of commitment constitute a force that binds the top management to a course of action deemed necessary for the success of an obligation.

With this line of reasoning, the concept of BIM commitment can be deduced. The predispositions, interventions, investments, obligations, pledge, responsibility, and perseverance that are required to initiate and sustain BIM adoption by the top management of construction organisations can be referred to as BIM commitment. In this case, BIM adoption is the obligation or the course of action. The top management of construction organisations must commit to the course of BIM adoption because construction organisations and construction employees are essential to the BIM implementation process. After all, construction organisations are the venue of the activities and duties of construction employees (Tezel et al., 2020; Chiu and Lai, 2020). The process of BIM requires the activities and duties of the construction employees to comply with the principles and requirements of BIM (Borrmann et al., 2018). Hence, for a successful BIM adoption in a construction organisation, the top management of the organisation must be committed to creating an enabling environment for BIM adoption and motivating its employees towards BIM adoption. This indicates that BIM commitments are essential to managing the transition, resistance, competency, organisational structure, organisational culture, and organisational resources in the course of the BIM implementation process.

Thus, this research describes BIM commitments as the total dedication of the top management of construction organisations to BIM adaptation, adoption, application, and implementation. This means that BIM commitments denote the willingness and readiness of the top management of construction organisations to allocate the organisational and managerial resources, such as money, time, culture, structure, and visions to the process of BIM adoption and adaptation in their organisations. Therefore, it can be argued that the level of BIM commitment of the decision-makers in a construction organisation is an indication of the importance attached to BIM adoption. This is because the importance attached to BIM adoption will be revealed through the readiness and willingness of the decision-makers to allocate the resources necessary to successfully execute the BIM transformation in their organisations. The importance attached to BIM adoption will also be revealed through the dedication and determination of the decision-makers to rise to the challenge posed by the BIM revolution in the construction industry. This argument greatly gives emphasis to the importance of BIM commitment as an essential BIM implementation strategy that could be adopted in the construction industry. However, the importance of BIM commitments to the BIM implementation process manifests in different forms.

Firstly, it determines the top management's obligations to providing an enabling BIM and works environment because it ensures the top management's willingness to go the extra mile and do whatever it takes for BIM adoption. It demonstrates the top management's conviction about BIM benefits and demonstrates the leadership potential of the top management. Also, BIM commitment serves as a way to respond to competitive pressure from BIM-compliant rival organisations. Secondly, BIM commitment determines the top management's obligations to support employees in transitioning to the BIM process. This will be made possible through the efforts that the top management will expend in securing the loyalty of their employees towards BIM adoption, as well as directing employees' behavior and attitude towards BIM adoption. The commitment of the top management to BIM adoption will lead to a healthy partnership between the employees and top management towards BIM adoption. It will also contribute to improving the understanding and performance of employees about BIM. Thirdly, BIM commitment determines the top management's obligation to sustain BIM adoption obligations by ensuring the perseverance, hard work, dedication, and enthusiasm of the top management towards BIM adoption.

There are challenges and difficulties that will be encountered in the BIM implementation process. However, BIM commitment will serve as insurance to BIM adoption regardless of the BIM adoption challenges and difficulties. With BIM adoption insurance in place, a more secure organisational climate will be created and the process of restructuring and transforming the organisational structure towards BIM adoption will be easy and smooth. Whichever way BIM commitment manifests, its importance in BIM implementation process, it is fundamentally clear that BIM commitment will ensure that the top management of construction organisations are voluntarily, non-retractably, consistently, and explicitly disposed to the provision of a pleasant BIM environment, training of employees on BIM skills and competencies, BIM vision and leadership, training of employees on BIM process, BIM-friendly organisational structure and culture, managerial resources that are required for a practical and consistent BIM adoption, and a leadership style that will build multidisciplinary collaboration culture.

The responsibilities imposed on top management by BIM commitment are huge; but the fact that construction organisations are constantly faced with ever-increasing competition means that the top management must be prepared for new challenges, changes, and upgrading. Also, there are competing demands on the top management commitments and the resources of an organisation. Therefore, the strength of the commitment of the top management towards BIM adoption further draws attention to the importance attached to BIM adoption by the top management. It also serves as a determinant of the success of BIM implementation process in the construction industry. In support of the argument for BIM commitment as an essential strategy for driving BIM implementation process, studies, such as Phang et al. (2020), Okakpu et al. (2020), Al-Saeed et al. (2020), Munir et al. (2020), and Sinoh et al. (2020), Siebelink et al. (2020), Awwad et al. (2020), Azzouz and Papadonikolaki, (2020), Olawumi et al. (2018), Almuntaser et al. (2018), Amuda-Yusuf, (2018), Chan et al. (2019), Yuan et al. (2019), Liao and Teo, (2019), Bosch-Sijtsema et al. (2019), Marefat et al. (2019), Liu et al. (2017), Ho and Rajabifard, (2016), Cao et al. (2017), Elhendawi et al. (2019), and Phang et al. (2020), have identified top management commitment as an important driving force for BIM adoption.

3.6.1.3 BIM capacity development

Capacity development has been described from the perspective of process and methodologies. As a process, Lavergne and Saxby (2001) defined capacity development as the process of obtaining, strengthening, and maintaining the capabilities to acquire relevant skills and knowledge. This definition is aligned to that of Bolger (2000), who described capacity development as a process of learning new skills to bring about changes in an organisation or to enhance the effectiveness and efficiency of an organisation. In support of the definitions provided by Lavergne and Saxby (2001) and Bolger (2000), Brinkerhoff and Morgan (2010) defined capacity development as the process by which people and organisations create and maintain capacity. The description of capacity development as a process suggests that maintaining the existing capacity of an organisation or employees will require a series of steps towards acquiring new skills and strengthening the existing skills.

As a methodology, Mackay et al., (2002) and Alaerts and Kaspersma, (2009) viewed capacity development as an empowerment strategy for individuals, leaders, and organisations. Kühl, (2009) defined capacity development as a skill improvement method for developing, managing, and maintaining organisational processes. The view of capacity development as a methodology by these authors emphasizes the use of capacity development as a strategy for improving the existing capabilities of an individual or a group of people. Given the above definitions, the elements of capacity development can be identified to include skills development, knowledge development, and acquisition of competencies. This means that a BIM implementation process or method that makes use of training, skills, knowledge, competencies, and literacy forces to drive BIM adoption can be referred to as BIM capacity development. From this description, BIM capacity emerged as a term that describes the abilities, skills, knowledge, understanding, and behaviors to function in a BIM environment.

Conceptualizing BIM capacity development as a process would indicate that BIM capacity development is the process through which BIM capacity is instilled in an individual or group of people. Also, it will indicate that BIM capacity development is a continuous skill and competencies improvement process of building a critical mass of human resources for BIM adoption and implementation. As a methodology, BIM capacity development will serve as the approach for developing BIM skills, BIM knowledge, and BIM competencies in construction professionals (present or future) or employees through the provision of access to BIM training and education. Accepting these arguments would mean that BIM capacity development can be broadly described as the process and methodology for bringing an organisation to the required level of BIM maturity in terms of BIM skills, BIM knowledge, BIM leadership, and BIM competencies.

To put it another way, BIM capacity development can be explained as consisting of hard and soft capacities development. The development of hard capacities will refer to the development of BIM skills, BIM competencies, and BIM knowledge. The development of soft capacities will refer to the development of BIM leadership skills and BIM management skills. The development of soft capabilities becomes essential because of the need for teamwork in organisations in project teams.

Several arguments can be put forward to support BIM capacity development as an essential strategy for driving the BIM implementation process. First of all, BIM capacity development is important for overcoming BIM adoption barriers because it creates the willingness and ability to explore BIM adoption, and provides a convincing and enticing motive to apply BIM on projects. The cost of BIM adoption has been reported to be a major BIM adoption barrier (Ahuja et al., 2020; Mostafa et al., 2020). BIM capacity development will significantly reduce the cost of BIM adoption, as it will maximise the effectiveness of BIM investments (Rogers et al., 2015).

Also, BIM capacity development will encourage the creation of BIM environments in construction organisations and will foster a sense of belonging and ownership of the BIM revolution (Uhm et al., 2017).). Secondly, BIM capacity development will ensure the availability of the required human resources for BIM adoption through the tailoring of human resources for different roles in BIM adoption, both in the present and in the future. The availability of BIM competent construction employees will strengthen the link between BIM adoption needs and BIM capacity of organisations. Also, it will minimize over-reliance on BIM consultants and encourage construction employees to realize their BIM potentials (Shahruddin et al., 2020). Thirdly, BIM capacity development will ensure the consistency and sustainability of BIM adoption. Without a doubt, BIM adoption challenges will occur; but through BIM capacity development, organisations will be able to manage BIM adoption, solve BIM adoption challenges, and maintain BIM adoption goals (Bozoglu, 2016; Shahruddin et al., 2020).

The construction business environment will continue to change as BIM evolves. With continuous BIM capacity development, organisations can maintain their relevance and functions in the BIM-induced business environment (Alhamami et al., 2020; Chamikara et al., 2020; Yusuf et al., 2016; Puolitawal and Forsythe, 2016; Jin et al., 2017; Mahamadu et al., 2020; Abbas et al., 2016; Ali et al., 2016). Lastly, BIM capacity development will improve the impact of BIM adoption on projects, which will bring about the realization of the full BIM benefits. The importance of BIM capacity development to the success of BIM implementation cannot be over-emphasized. According to Abdirad and Dossick (2016), Chen et al. (2020), and Uhm et al. (2017), BIM capacity development will create the availability of BIM competent professionals that will be able to manage and provide the organisational, technical, technological, institutional, and resource capabilities that are required for a successful BIM adoption. Likewise, Papadonikolaki (2018) maintained that, without the development and maturity of BIM capacity, construction organisations and professionals cannot adopt BIM.

3.6.1.4 BIM utilization

BIM utilization depicts the efficiency and effectiveness of BIM application on construction projects (Succar and Kassem, 2016; Sarkar et al., 2015; Mesároš et al., 2020). This implies that strategic measures and systems are required for a practical BIM application or usage on construction projects (that is, to maximise the performance and benefits of BIM adoption). It also implies that construction organisations and professionals must work more efficiently when using BIM owing to the resources and time that BIM adoption demands. Also, BIM utilization represents the peak level of BIM performance that achieves the highest level of BIM benefits while utilizing the least amount of resources. This draws attention to the importance of conserving resources for BIM application while ensuring an acceptable level of BIM benefits.

However, balancing the effectiveness and efficiency of a BIM application is difficult in practice. This difficulty will be resolved through a strategic and contingent BIM adoption (Eriksson, 2015; Han and Golparvar-Fard, 2015; Han et al., 2015; Boton et al., 2015; Cao et al. 2015). According to Jin et al. (2015), Isaksson et al. (2016), Zhu and Mostafavi (2017), Liu et al. (2017), and Smits et al. (2017), a strategic and contingent BIM adoption will be achieved by adopting the following techniques. First, BIM application must be aligned with the planned BIM benefits and value, must comply with market values, must not be excessive, must be sustainable, and must be linked to project characteristics (client's expectations, project size, project complexity, team size, and team capability). Second, BIM tools and principles must be applied to the most valuable project activities, tasks, and processes. Third, scarce resources must be allocated appropriately and unnecessary efforts not wasted on BIM application. Fourth, BIM goals and objectives must be achieved with the allocated resources and at minimum cost. Fifth, BIM performance on projects must be in line with the project needs and BIM objectives. Lastly, BIM supply chain members must be productive.

In sum, BIM utilization describes the appropriate extent of BIM application on a construction project. There are points at which BIM application on a project becomes ineffective (Cao et al., 2015; Won and Lee, 2016; Dakhil et al., 2016). These points must be determined based on project complexity and expectations. For example, a highly complex project requires a higher level of BIM application compared to projects with low complexity, such as low-budget residential buildings. Also, a practical and efficient BIM utilization is determined based on the comparison between the extent of BIM investment (such as resources, time, and money) and the extent of BIM benefits realised. This means whether the BIM benefits realized adequately tally with or exceed the BIM investment. At this point, the level of BIM application becomes practical and the cost of BIM adoption becomes affordable (Zou et al., 2017). Therefore, BIM utilization is posited to be an important element in a BIM implementation model, where success, sustainability, and performance efficiency of BIM adoption are to be realized. The study by Lee et al. (2019), Hadzaman et al. (2015), Smits et al. (2017), Becerik-Gerber and Rice (2010), and Lau and Kong (2008) provide support for the concept of BIM utilization as an essential BIM implementation strategy. For example, Lee et al. (2019) developed building information models for alignment-based civil infrastructures and identified the partitioning of the building information models according to the level required by the end-users as an efficient way of utilizing BIM on construction projects.

3.6.2 Reduction in BIM adoption barriers

BIM adoption barriers are the obstacles or factors that frustrate the BIM implementation process (Mostafa et al., 2020; Rogers et al., 2015; Babatunde et al., 2020; Herr and Fischer, 2019; Mamter et al., 2017; Oesterreich and Teuteberg, 2019; Siebelink et al., 2020; Shirowzhan et al., 2020; Charef et al., 2019; Herr and Fischer, 2017; Shibani et al., 2020). In other words, BIM adoption barriers refer to the absence of the features of BIM implementation in the particular construction industry. This implies that the availability of some of the features of BIM implementation in the construction industry is an indication of a reduction in BIM adoption barriers (that is, the progressive overcoming of BIM adoption barriers).

Based on this understanding, it becomes clear that the progress of the BIM implementation process depends largely on how the thresholds or levels of reduction in BIM adoption barriers have been planned. It also becomes clear that there must be a system to track whether the construction industry is overcoming the barriers to BIM adoption. In this research, the term *reduction in BIM adoption barriers* was conceptualised to describe the measurable variables for tracking the level of reduction in BIM adoption barriers. The indicators of a *reduction in BIM adoption barriers*, according to McAuley et al. (2013), will provide a benchmark for BIM implementation because they draw attention to the BIM adoption barriers that are integral above all others in providing insights on BIM implementation process and how it can be pursued. In addition, the indicators of a *reduction in BIM adoption barriers* will create BIM implementation thresholds in the industry, provide a means of assessing the effectiveness of the BIM implementation strategies, and make provisions for market size and production capacity in the construction industry.

3.6.3 Level of BIM adoption on construction projects

The adoption of BIM on construction projects depicts the process or act of putting BIM tools, technologies, processes, and principles to use in the planning and execution of construction projects (Enegbuma et al., 2015; Herr and Fischer, 2019). The level of BIM adoption on construction projects has been linked to the degree of BIM implementation in the industry (Cao et al., 2014; Mahalingam et al., 2015; Aibinu and Venkatesh, 2014). This research conceptualized the level of BIM adoption on construction projects to consist of *criteria for BIM performance assessment, type of BIM capacity, type of BIM tools, type of building information models (BIM) developed,* and *level of objects' clarity*.

In project delivery, *criteria for performance assessment* provide an accurate reflection of project performance, increased complexity of construction projects, increased competitiveness of the construction business environment, increased sophistication of the construction technologies, and effectiveness of project management systems (Neyestani, 2016). The project management system provides tools to coordinate the technologies, processes, and people required for delivering a construction project so as to maximize the project's chance of success (Babu and Sudhakar, 2015). This means that the performance of a project management system depends on the efficiency and effectiveness of the technologies, processes, and people (Cheong and Mustaffa, 2017).

Khalfan et al. (2015) and Yusuf et al. (2016) have described BIM as the new technological standard in construction information development, the new efficiency standard in the construction industry, and the new performance standard for construction projects. This connotes that BIM qualifies as a project management system because of the usefulness of its tools and processes for project planning, monitoring, and control (Peterson et al., 2011; Rokooei, 2015). In support, Travaglini et al. (2014) conclude that BIM provides a system for construction management practices because it allows the visualization and understanding of project information and management of project participants. In effect, the performance of BIM on construction projects indirectly reveals the level of BIM adoption on the projects.

Equally, the extent of BIM supply chain networks and the number of building information models to be developed have been identified as the determinants of the extent of BIM application on construction projects (Eriksson, 2015; Oraee et al., 2017). The implication of this, according to Vidalakis et al. (2011), is that the supply chain network in BIM-based construction projects must include only the members who have substantial involvement, responsibilities and direct contributions to BIM processes in terms of authoring of building information models, information sharing and exchange, and knowledge transfer. In support, Baiden et al. (2006) observed that the higher the complexity of a construction project, the higher the number of team members required, and the higher the collaboration required because of the increase in the numbers of building information models to be developed.

These requirements also have a significant impact on the intensity of BIM adoption on projects (Ciribini et al., 2016). In the same way, the extent of BIM supply chain network and the number of building information models to be developed have been explained to be based on the BIM capacity of the BIM supply chain members, the extent of integrating building information models, level of development (LOD) of building information models, and level of clarity of the parametric objects in the building information models (Fai and Rafeiro, 2014; Solihin and Eastman, 2015; Han and Golparvar-Fard, 2015; Cao et al., 2015; Leite et al., 2011). This evidence shows that the intensity of BIM adoption on construction projects relates to the type of BIM capacity, type of BIM tools, level of objects' clarity, and type of building information models developed for the projects.

Cao et al. (2015) substantiated this claim by stating that a higher level of integration is an indication of a higher level of BIM application because high BIM capacity and high LOD are required to develop a fully integrated building information models. LOD is a fundamental issue in BIM application. It refers to the richness of the representation, specifies the content and reliability of information models in BIM, and determines the characteristics of model elements of different building systems and components (Fai and Rafeiro, 2014). LOD ranges from 100 to 500 but the choice of LOD depends on the specific needs of construction projects (Boton et al., 2015). LOD 100 represents components with a symbol or as generic elements without defining their specific properties (Han and Golparvar-Fard, 2015) while LOD 200 is an approximate representation that only shows the shape, approximate quantities, location, and orientation, and allows some non-graphic information to be attached (Solihin and Eastman, 2015).

These limitations make LOD 100 and 200 insufficient for a higher level of integration (Han et al., 2015). LOD 300 is sufficient for the design development phase of projects because of its usefulness in generating construction documents (Boton et al., 2015). It is a precise geometry that uses specific objects and shows the precise size, shape, location and orientation, and information on interfaces with other systems (Solihin and Eastman, 2015). LOD 400 represents details of assemblies as they appear in shop drawings (Leite et al., 2011), and contains the information required for assembly, installation, and fabrication (Solihin and Eastman, 2015). LOD 500, on the other hand, is a field-verified representation that provides sufficient details for planning, operation, and maintenance of construction projects. However, some building components require more or fewer details, which implies that LOD must be standardized for BIM depending on project expectations or BIM capacity**.** Although the higher the LOD, the more detailed the information (Solihin and Eastman, 2015), it is not necessary to model all building information to high LOD (Boton et al., 2015). Based on this understanding, it can be concluded that the LOD of building information models and the level of clarity of the parametric objects in the building information models are significant indications of the level of BIM adoption on construction projects.

3.6.4 Levels of integration and collaboration among the BIM-SCM

This research theorized *network communication, knowledge sharing, and transfer, information sharing and exchange,* and *trust-based relationships* to be the indicators of the levels of integration and collaboration among the BIM-SCM.

3.6.4.1 Trust-based relationships

Trust-based relationships among the BIM-SCM were considered as a form of integration and collaboration because trust is essential to successful interactions and dispositions among the construction project supply chain (Alreshidi et al., 2017; Papadonikolaki et al., 2015; Liu et al., 2017). Trust has been confirmed to be essential for achieving flexibility, ensuring a smooth flow of information, and ensuring effective collaboration in the construction project supply chain (Manu et al., 2015; Neubert et al., 2018). Chiniara and Bentein (2018) and Zhang et al. (2019) noted that trust is an interaction that indicates a positive perception of an intention to behave in a trustworthy manner, thereby causing the development and protection of the team spirit by providing cooperation and solidarity among team members. Wu et al. (2017) emphasized that trust has a positive impact on conflicts, costs, and team effectiveness. This has led to the description of a *trust-based relationship* (TBR) as an interactive process on which trusting behavior develops because its development is influenced by the characteristics of construction projects and the nature of relationships in construction projects (Papadonikolaki et al., 2016; Ghaffarianhoseinin et al., 2017; Liu et al., 2016; Alreshidi et al., 2017). However, the characteristics of construction projects and the nature of relationships among the project participants have an impact on trust development among the project participants (Rezvani et al., 2018; Manu et al., 2015; Zhang et al., 2018).

Construction projects are temporary, unique, limited by time, and characterized by a high number of participants; while the nature of relationships in construction projects is such that the participating members have to work with new, old, unfamiliar, and heterogeneous members. The effect of this type of relationship on trust development is significant because there may be no history of interactions, dispositions, and priorities among the members, which is imperative to trust development (Buvik and Rolfsen, 2015). Without trust development, opportunistic behavior, such as motive to maximise one’s self-interest, failure to interact, reluctance to check the clarity of information, professional stereotypes, poor communication, and misuse of information, would be prevalent among the project participants (Jagtap and Kamble, 2015). Therefore, ensuring the absence of these behavioral problems in relation to the collaborative requirements of BIM process means that certain cooperative behaviors, such as reliability, promise fulfillment, and fairness, are expected of the BIM-SCM (Rokooei, 2015; Williams, 2016; Tsiga et al., 2016; Cheong and Mustaffa, 2017).

Talavera (2013) claimed that collaborative requirements of the BIM process as manifested in cooperative behaviours are founded on trusting and trustworthy behaviors because they refer to the absence of behavioral problems in that they prevent the BIM-SCM from pursuing personal or professional interests and misuse of shared information. This implies that a BSC is automatically formed in BIM-based construction projects and that the BIM-SCM is expected to avoid the exploitation of opportunities for the pursuance of self-interest.

In so doing, the BIM-SCM is obligated to undertake TBR for decision-making, information model development and exchange, communication, and collaboration. This will enable the BIM-SCM to understand their respective responsibilities in the BIM process and to understand each other’s needs and concerns, thereby guaranteeing a successful construction project delivery (Talavera, 2013). The responsibilities in the BIM process cut across roles, competencies, ethics, skills, and contractual relationships (Husain, Razali, and Eni, 2018). These responsibilities enable TBR among the BIM-SCM and include risk sharing, cross-functional cooperation, the competence of personnel and organisation, problem-solving ability, openness in sharing information, lack of confrontation and adversarial relationships, work, and social interaction, conflict resolution, and absence of competing interests (Mikapagaro and Germin, 2018).

In addition to the responsibilities in the BIM process, certain one-off positive attributes, such as honesty and mutual commitment, are required to initiate the process of trust development at the early stages of the BIM-based construction projects. This must be followed up with a consistent exhibition of some unique positive and trustworthy attributes, such as integrity. As pointed out by Jiang et al. (2016), integrity is a function of circumstances and opportunities; if it does not happen consistently, then the individual or organisation in question cannot be said to possess integrity.

It becomes evident that BIM is a process involving lots of relationships and that trust development in these relationships will not be smooth without consistent adherence to BIM principles and requirements, such as integrity, mutual rewards, and benefits, a spirit of cooperation, absence of competing interests, social and work interactions, absence of racist and tribalistic behavior, and problem-solving abilities. This means that, without consistent integrity, there is no foundation on which TBR can be built. This is because consistent integrity makes a person or an organisation trustworthy and dependable.

Similarly, Mathews et al. (2018) reported that BIM application on projects creates a BSC where a network relationship is formed from hierarchical relationships, which lead to mutual rewards and benefits. Mutual rewards and benefits find a place in TBR among the BIM-SCM because, when all the members are interested in contributing value to the BIM process and expecting advantages that correspond to their respective value, then the trust will effortlessly develop among them. The finding by Olatunji (2015) indicates that BIM-SCM is expected to have a spirit of cooperation that will eliminate the functional and traditional adversarial relations among them. This is because confrontations and adversarial relationships occur when the people or organisations on the BSC are opposing each other, which will create oppositional relationships that are devoid of trust and will affect project performance. This means that a lack of confrontation and adversarial relationships will ensure TBR.

Matthews et al. (2018) confirmed that the absence of competing interests among the BIM-SCM is important to achieve collaboration in the BIM process and this will be achieved when the BIM-SCM share common interests and problems through regular interaction. Also, certain accidental, regulated, repeated, and regular social and work interactions must occur between the BSC. Such interactions allow the members to make positive contributions to the project at hand through their actions and reactions. Liu et al. (2017) confirmed that there is a need for frequent social and work interactions in BIM-enabled collaboration among the BIM-SCM in order to stimulate the trust effects of BIM application on projects.

In the BIM process, when a dispute arises, as it must, efforts to facilitate the peaceful ending of the dispute or conflict are expected of all BIM-SCM. Doing so does not only signify professional growth, but also the existence of TBR. More importantly, competence is a major expectation among the BIM-SCM because it enables the members to have confidence in the information models and reviews to be shared by the other members (Liu et al., 2017).

Alreshidi et al. (2018) maintained that problem-solving abilities, such as active listening, analytical skills, and team-building skills, are highly useful and inevitable in TBR because they enable the BIM-SCM to share their views on the conflict issues and the likely resolution tactics. Carvalho et al. (2019) and Kuiper and Duffield (2018) observed that BIM-SCM are expected never to exhibit behaviors that stem from strong loyalty to a tribe or social group or a race because racist and tribalistic behaviour will promote prejudices, discrimination, and antagonism, which will frustrate TBR.

3.6.4.2 Information sharing and exchange

Information Sharing and Exchange (ISE) has been identified as the foundation of collaboration in the BIM supply chain (Boton and Forgues, 2018). ISE has also been identified as essential to valued and informed decision-making, real-time transmission and processing of information, optimization of the supply chain, speed-up of information flow, information coordination, and sense of ownership (Lee et al., 2018; Jin et al., 2018; Zhao et al., 2018). Specifically, Boton and Forgues (2018) explained that ISE is an important BIM principle and process that is required for the integration of the project participants and project information. In the BIM process, the BIM-SCM is required to collaborate on the development of project information so as to make project information more predictable and visualized through rigorous analysis, simulation, and modelling (Azhar et al., 2008).

Solihin et al. (2016) noted that the quintessence of ISE among the BIM-SCM is the creation of a federated building information model because it is a shared and centralized database of integrated discipline-specific building information models that could only be achieved by file-based or server-based file linking. This requirement of the BIM process has heightened the need for ISE among the BIM supply chain members by making building information models the source of project information (Boton and Forgues, 2018). Therefore, it becomes important for building information models to be reliable and dependable because the information they provide is required to inform the BIM-SCM, support decision-making, serve as project documentation, and represent the project plans (Banerjee et al., 2005; Biffl et al., 2007; Cinque et al., 2007).

In addition to the need for reliability and dependability of building information models, the complexity of the construction process and, more importantly, the BIM process requirements make it important for information to flow smoothly among the BIM-SCM (Uden and Naaranoja, 2007; Hooper and Ekholm, 2010). Hooper and Ekholm (2010) further pointed out that ISE is critical to BIM application on construction projects because it determines the future use of building information models, the level of BIM application on projects, the extent of collaboration and integration among the BIM-SCM, and the development and richness of the federated building information models.

Sacks et al. (2010) described ISE as a requirement in BIM because the discipline-specific building information models developed by the BIM-SCM are not sufficient in themselves; the discipline-specific building information models must be shared, transferred, and integrated in order to fulfil the information needs of the members and to develop the federate building information model. Fox and Hietanen (2007) stated that ISE is a BIM process requirement because the information content of a building information model becomes more useful for the BIM-SCM and discipline-specific purposes when it is exchanged, shared, checked, combined, and updated with other building information models. These explanations support the position of ISE as a factor of integration and collaboration among the BIM-SCM.

More importantly, BIM process requires that BIM-SCM author discipline-specific building information models that are void of errors or clashes and that can be integrated (Lee et al., 2015; Abanda et al., 2015). The attending implications of this requirement are that the responsibilities of the BIM-SCM have been extended to include compulsory information supply, compulsory information demands, the offering of professional inputs, participating in reviews, and participating in cross-referencing (Fox and Hietanen, 2007). Failure to undertake these additional responsibilities by the BIM-SCM will pose a threat to the seamless flow of ISE. Another essential point is the conclusion by Hooper and Ekholm (2010) and Boton and Forgues (2018) that the smooth flow of ISE among the BIM-SCM depends on the sharing and exchange of the expected quality and form of information models.

Furthermore, previous studies indicate that the components of information sharing and exchange include the use of consistent data structure and definitions, non-withholding of information, non-distortion of information, clarity of information, high quality of information, adequacy of information, timely sharing of information, the accuracy of the information, credibility of information, flawless information exchange, exchange format, data interoperability, exchange channel, data integration, and absence of conflicting information

(Hooper and Ekholm (2015; Siugh et al., 2019; Choi et al., 2015; Ramaji and Memari, 2016; Venugopal et al., 2015). This is because server-based data interoperability enhances collaborative behaviours among the BIM-SCM, the inter-organisational use of federated building information models depends on the creation of shared building information model repositories with concurrent access, and the use of collaborative electronic media is important to the consistency of the federated building information model across the BIM supply chain (Solihin et al., 2016).

3.6.4.3 Network communications

Communication refers to the transmission of resources from one party to another using shared symbols and media; and it is essential to the efficient performance of the project participants because of the difference in their skills, competence, interests, and organisation structure (Wu et al., 2017). Barlish and Sullivan (2012) build on this conclusion, stating that communication is crucial for problem-solving, decision-making, integration and collaboration, understanding, dispute-resolution, project objectives determination, and efficient coordination. In the BIM process, communication among the BIM-SCM is about the transmission of project information, such as data, opinions, ideas, skills, technology, and feedback. BIM provides structure and control for communication process and practice; thereby ensuring effective communication of project information (Dubas and Paslawski, 2017).

BIM also turns multi-disciplinary project participants into a BIM supply chain by subjecting the participants to BIM processes and principles (Nawi et al., 2014; Wu et al., 2017). Specifically, Wu et al. (2017) explained that the BIM process requires the communication of resources, such as data, information, and knowledge. This requirement complicates the communication process and alters the nature of communication among the BIM supply chain (Dubas and Paslawski, 2017). Thus, ensuring effective communication of resources among the BIM-SCM means that the members must be interconnected in all directions of the chain network (Fiala, 2005). This interconnection is achieved in BIM process with an electronic collaborative network (e-mail, teleconferencing, mobile phones, internet, multimedia, virtual reality, and intranet) and network structures (contractual relationships, coordination, integration, and collaboration requirements) (Cheng et al., 2001; Charalambous et al., 2013). The above descriptions indicate a unique form of communication in the mode of an organized and controlled communication among the BIM-SCM that takes place via an electronic collaborative network and network structures.

Also, studies, such as those by Bassanimo et al. (2013), Charalambous et al. (2013), and Bassanino et al. (2013), have shown that, for communication to be effective among the BIM supply chain, it must take place across the project lifecycle, must take place across different communication facets, and must compose of different methods of transmitting resources among the BIM supply chain. For instance, Anumba and Exbuomwan (1999) inferred that communication across facets, such as interpersonal, inter-group, intra-group, inter-professional, intra-organisation, inter-organisational, and among team members, is essential to integration. This connotes that communication across different facets becomes more essential among the BIM supply chain owing to the need for integration and collaboration in the BIM process and because groups and teams are generally formed from several specialist organisations in the BIM supply chain to undertake BIM-related tasks.

Cheng et al. (2001) found that communication across different facets among the supply chain members is essential to the carrying out of the normal practices of individual organisations, such as information generation and management, planning and control, and decision-making. According to Dike and Kapogiannis (2014), cross-functional and cross-organisational communication are some of the ways by which the BIM process alters the nature of communication among the BIM supply chain. In addition, Meng (2012) established that the BIM process requires the BIM supply chain members to keep open communication, and described open communication as a form of communication that permits a multi-directional flow of resources. Porwal and Hewage (2013) observed that in BIM, the multi-directional flow of resources among the BIM supply chain means that each member grants the other members a non-exclusive license to reproduce, distribute, display, or otherwise use that member's contributions for the needs of the project.

In sum, these explanations describe a pattern of communication among the BIM supply chain that consists of different communication facets, takes place across the project life-cycle, contains mixed methods of transmitting resources, occurs at different places at the same time or the same place at different times, as well as demonstrates the collaboration and integration requirements of BIM process.

Furthermore, the BIM process requires the planning for communication channels, communication platforms, communication protocols, structured e-meeting, real-time communication, and joint problem-solving techniques among the BIM supply chain (Bassanino et al., 2013; Buvik and Rolfsen, 2015). This serves as a manifestation of a clearly defined communication process. According to Cheng e al. (2001), the use of communication channels such as meetings, discussion, and communication technologies enhance communication flow and promote better understanding among the BIM supply chain. This suggests that the effectiveness of the communication process is made possible by the BIM process requirements, such as use of communication protocols, which give structure and consistency to the communication process (Charalanbous et al., 2013). A case study of communication among the BIM supply chain by Al-Hattab and Hamzeh (2013) confirmed that BIM process requirements ensure the occurrence of overlapping interaction, flexible formalities, and transparency in the communication process. This observation unveiled another form of communication in the BIM process that takes place across clearly defined channels, platforms, protocols, time-space, and objectives.

Collectively, the nature and forms of communication among the BIM supply chain members represent a *network communication,* and it is characterized by regular communication among the team and groups within the BIM supply chain organisations, as well as across the stages in the project life-cycle. This regular communication must be reciprocated, allow feedback, be multi-dimensional, and happen in real-time.

3.6.4.4 Knowledge sharing and transfer

Knowledge represents intangible assets, technical solutions, experiences, ideas, innovations, expertise, know-how, feedback, and creative processes that are held by one person or embedded in groups of people (Lee et al., 2010). Knowledge may be stored as mental models (that is, tacit knowledge) or stored as manuals, documents, or databases (that is explicit knowledge) (Politis, 2003; Ho et al., 2013). Similarly, knowledge may be individual (that is, held by one person) or collective (that is, embedded in groups of people) in nature (Cheng and Fu, 2013). Collective knowledge emerges out of collaboration and it is more relevant to the supply chain network. However, without the sharing and transfer of knowledge, collective knowledge may not be achieved (Lee et al., 2010).

Knowledge is deemed to be shared and transferred across the supply chain network when ideas, innovations, and expertise are leveraged in order to concentrate on supply chain activities or capture the project objectives (Chen et al., 2014). In the construction industry, knowledge sharing transfer is essential to the successful delivery of construction projects (Uden and Naaranya, 2007). This is because knowledge sharing transfer ensures effectiveness and coordination in project delivery (Cheng and Fu, 2013), sustains competitive advantage among construction organisations (Renzl, 2008), enables the development of new skills and competences among the construction professionals (Renzl, 2008; Uden and Naaranoja, 2007), and allows project participants to expand their resources pool, deliver value-added services, and develop in-depth cooperation (Chen et al. 2014).

Knowledge shared and transferred in the BIM supply chain relates to a reciprocal process of sharing and exchanging ideas, innovation, expertise, or feedback among the BIM-SCM (Li et al., 2017; Zhong et al., 2017; Wang and Meng, 2018). According to Ho et al. (2013), the actual process of knowledge sharing and transfer among BIM-SCM occurs through formal and informal discussions, reviews, teamwork, building information models, project databases, project proceedings, insights and comments, and reports. This establishes knowledge sharing and transfer as a major objective of integration among the BIM-SCM, and as a significant contributor to the efficiency and effectiveness of BIM application on construction projects (Zhong et al., 2017).

Although, not all construction knowledge goes into the BIM process or development of building information models (Arayici et al., 2012; Alsehrawy et al., 2018), but they certainly have an impact on the BIM process and the development of building information models (Laan et al., 2011; Arayici et al., 2012). This is because, in BIM process, knowledge sharing and transfer are required to pool all the project support information for project delivery and facilitate the utilization of construction knowledge in BIM process through the optimization of information collection, interoperability, information flow, and information retrieval (Chen et al., 2014). This implies that there is BIM-related knowledge. Lin (2014) and Howard and Bjork (2008) describe BIM-related knowledge as reports, comments, drawings, documents, process records, problems faced and solved, expert suggestions, know-how, innovations, notes on experience, and design intentions. In support, Liu et al. (2013) concluded that the sharing of building information models and the extraction of information from the building information models serve as the core of knowledge sharing transfer among the BIM-SCM.

Additionally, Cheng et al. (2018), Ding et al. (2016), and Li et al. (2017) concluded that, to enable collaborative resource coordination and integration among the BIM-SCM, *knowledge sharing and transfer* must occur from one person to another (inter-personal knowledge sharing and transfer) or from a workgroup to another (inter-professional, inter-organisational, inter-group, and inter-team knowledge sharing transfer). Studies by Liu et al. (2013) and Lin (2014) provide support for this argument by concurring that it is a BIM best practice for construction knowledge to be extracted as a building information model because BIM-related knowledge is easily understood in the form of a model and not as text-based illustrations.

In conclusion, the documentation, sharing, and transfer of BIM-related knowledge as building information models is a major theme in knowledge sharing and transfer among the BIM-SCM owing to the limited number of BIM-based construction projects (Goh, 2002). Another major theme in knowledge sharing and transfer among the BIM-SCM is the extraction of BIM-related knowledge from building information models. This is because building information models retain BIM-related knowledge in a digital format, facilitate easy updating and transfer of BIM-related knowledge, and enable the documentation, integration, and reuse of BIM-related knowledge (Lin, 2014; Poreal and Hewage, 2013). Several studies have provided pieces of evidence for knowledge sharing and transfer among the BIM-SCM as an essential dimension of integration and collaboration among the BIM-SCM. For example, Ho et al. (2013) identified the willingness to share resources, insights, and comments as a form of integration and collaboration among the BIM-SCM. Arayici et al. (2002) noted that BIM is a new way of working in the construction industry and that the sharing and transfer of past experiences or lessons learned on the past BIM-based projects are required among the BIM-SCM in order to develop an in-depth of understanding of the BIM process.

3.7 Summary of theoretical and conceptual framework

The preceding sections in this chapter have presented the theoretical framework, theoretical model, conceptual model, hypothesised model, and conceptual background for the research. The chapter explained the derivation of the theoretical framework and model for the research from the implementation process theory modified with BIM-related postulations. The chapter also explained how the theoretical model facilitates the understanding of the concepts and variables associated with a successful and sustained BIM implementation. The explanations for the conceptual model and conceptual background, as presented in this chapter, cover the levels of integration and collaboration among the BIM supply chain members as measured by *trust-based relationships, network communication, information sharing and exchange*, and *knowledge sharing and transfer*; BIM implementation strategies as measured by *BIM motivation, BIM commitment, BIM capacity development*, and *BIM utilization*; reduction in the barriers to preliminary and sustained BIM adoption; and level of BIM adoption on construction projects as measured by *criteria for BIM performance assessment, type of BIM capacity, type of BIM tools, type of building information models (BIM) developed*, and *level of objects' clarity*.

CHAPTER FOUR

RESEARCH METHODOLOGY

4.1 Introduction

This chapter explains the research philosophy, research paradigm, research design, research methods, and research ethics. Further explanation is provided on questionnaire design, interview design, data collection methods, data analysis methods for the quantitative data, and data analysis methods for the qualitative data.

4.2 Research philosophy

The philosophical foundation for research must comprise of the philosophical orientation, research paradigm (methodological approach), and research approach (Aliyu et al., 2015). The philosophical orientation of research signifies the point of departure for framing the research methodology for educational research (Goertz and Mahoney, 2012). There are two major types of philosophical orientations: epistemology and ontology (Goertz and Mahoney, 2012; Kant, 2014). According to Goertz and Mahoney (2012), epistemology is a philosophical analysis that makes it possible to gain knowledge of reality. Kant (2014) builds on this definition by stating that epistemology is a philosophical analysis that describes what can be known and what criteria can be used to justify what can be known as knowledge.

Holt and Goulding (2014) relate epistemology to forms or types of knowledge. The epistemological positions that can be used to frame the research methodology for research include empiricism (the assumptions that the knowledge of reality is based on sensory experience) and rationalism (the assumptions that the knowledge of reality is based on reason). Kant (2014) describes ontology as a philosophical discipline that deals with the nature of reality or existence. Aliyu et al. (2015) follow a similar view and describe ontology as a catalogue of vocabulary for representing knowledge or classification of entities that are assumed to exist in a domain of interest.

In like manner, Holt and Goulding (2014) note that ontology deals with physical, social, and technical support on which, and in interaction with which, knowledge is created. Holt and Goulding (2014) identified ontological positions to include idealism – the assumptions that the external world is just appearances, realism or objectivism – the assumptions that the external world consists of natural and social existence, and relativism – the assumptions that the external world is a social construct. The definitions provided by Goertz and Mahoney

(2012), Kant (2014), Holt and Goulding (2014), and Aliyu et al. (2015) have set parameters for understanding the philosophical orientation of educational research. These definitions made it clear that ontology is concerned with what there is to know and epistemology is concerned with how we can know what there is to know. This means that the ontological position of research serves as a presupposition for the epistemological position of the research.

Another important component of the philosophical foundation for the research is the research paradigm. A research paradigm is a concept of philosophical investigations via an appropriate methodological approach (Johnson and Onwuegbuzie, 2004). Examples of a research paradigm that provide the methodology for philosophical investigations are pragmatism, interpretivism, subjectivism, critical theory, conflict paradigm, functionalism, naturalism, Marxism, Neo-Marxism, existentialism, and post-modernism (Asghar, 2013; Müller-Doohm, 2017; Therborn, 2018; Peters and Schwenke, 2000). The last component of the philosophical foundation for the research is the research approach. The research approach has been described as the collective set of procedures and techniques for understanding and explaining a research subject or phenomenon of study within a particular philosophical investigation (Aliyu et al., 2015).

According to Aliyu et al. (2015), there are three basic ways of approaching research: positivism – the view that knowledge is produced through facts and evidence, post-positivism – the view that knowledge is produced through testing propositions, and constructivism – the view that knowledge is produced by constructing meaning for it through exploration and understanding. Therefore, the philosophical foundation (orientation and position) underpinning the research design for this study comprised of realism (the ontological position), empiricism (the epistemological position), pragmatism – interpretivism – subjectivism (the methodological approach), and positivism (the research approach) (see Figure 4.1).

The ontological position deals with the nature and form of the phenomenon under study, hence this research investigated the reality of BIM implementation, adoption, and collaboration through the experience and reasoning (realism) of the direct participants of BBCPs. The epistemological position is about the assumptions to be made so as to understand the phenomenon under study. Thus, this research emphasised empirical evidence (empiricism) as essential to understanding BIM implementation, adoption, and collaboration among the direct participants of BBCPs. The methodological approach addresses the conceptualisation of the phenomenon under study.

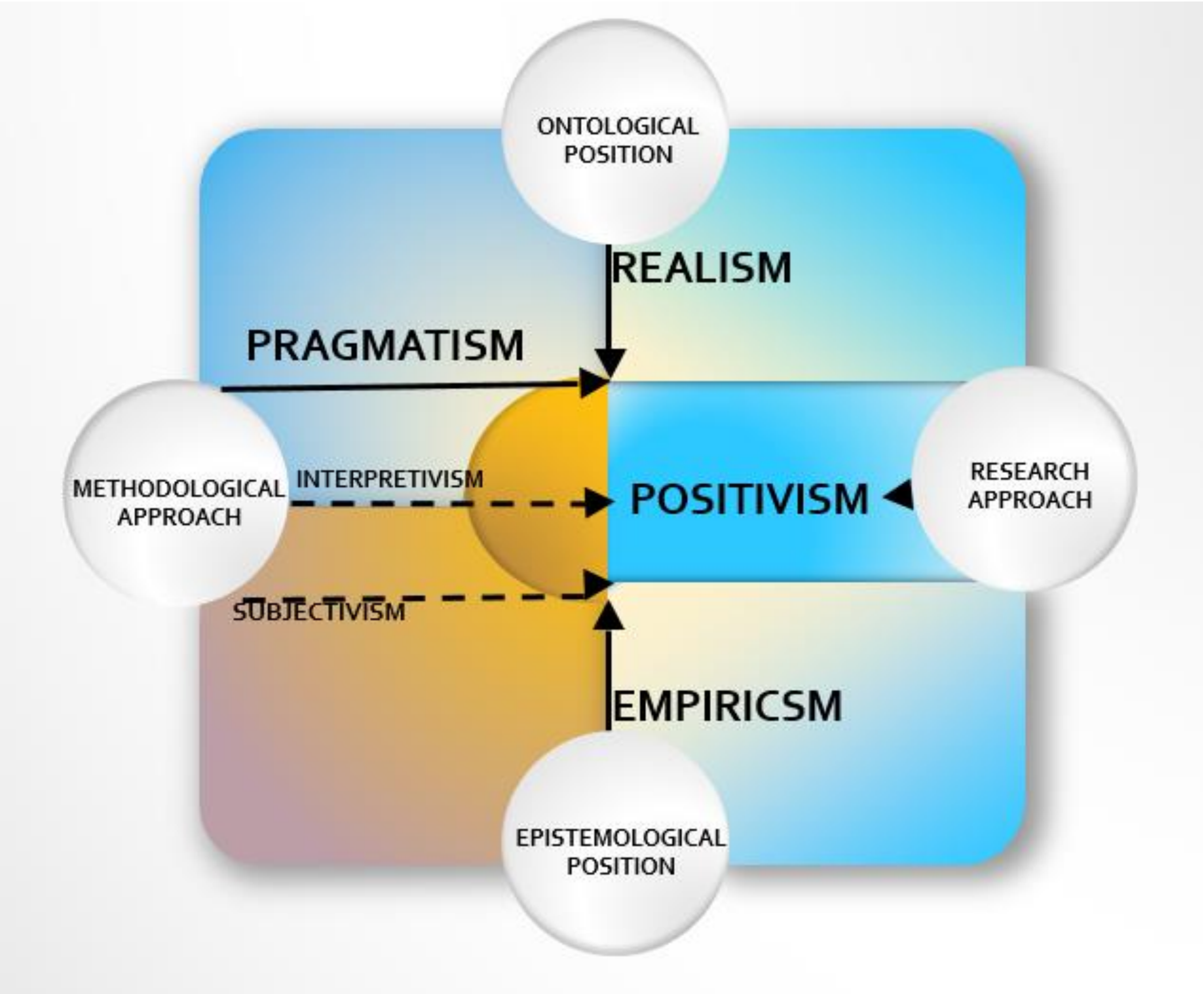

Figure 4.1: Philosophical orientation and position for the research

Pragmatism proposes the use of a philosophical and methodological approach that is appropriate for the research question (Kaushik and Walsh, 2019). It focuses more on the research question because it is mainly concerned with how research design and research methods are mixed to answer the research question (Brush, 2020; Shields, 1998; Kitcher, 2012; Hickman, 2001). Pragmatism focuses more on the research question rather than on the research methods; holds that human actions are based on their past experiences, beliefs, and intelligence; and is associated with mixed-methods research design (Ulrich, 2007; Kadlec, 2006; Koopman, 2006). Biesta (2010) and Frega (2014) argued for the use of pragmatism as a philosophical and the conceptual tool for solving the research question because it supports the use of intelligent action in research, such as the creation and testing of hypotheses, and identifies the use of multiple theoretical perspectives as an important strategy for inquiry.

In pragmatism, the best methodological approach for research is the approach that is most effective in producing the desired consequences of scientific inquiry (Brush, 2020). Related to this view, Midtgarden (2012) concurred that pragmatism enables the fitting together of the insights provided by qualitative and quantitative methods through the combination of research methods and research philosophy (Aboulafia et al., 2012). Kilpinen (2008) explained that pragmatism endorses the use of practical theory with a focus on practical consequences. The common research methods associated with pragmatism include interviews and surveys (Hall, 2013; Harrison et al., 2017). Also, it has been pointed out that the philosophical underpinnings of pragmatism include (a) recognising a research problem, (b) formulation of the research question from the research problem, (c) developing a research design to address the research question, (d) choosing the best research method for the research design, and (e) conducting the research (Onwuegbuzie et al., 2009; Yvonne Feilzer, 2010).

Interpretivism is a paradigm that enables the understanding of a complex phenomenon through an interactive interview and the collection of valuable data that provide better insights. The interpretivism perspective brings a deeper understanding of the phenomenon, provides unique content for understanding the complexity of a phenomenon, and allows a research method, such as interview, to be leveraged for the investigation of things that are beyond the scope of the other research methods (Wynn and Williams, 2012; Roth and Mehta, 2002; Clear and MacDonell, 2011). For example, the thoughts, views, prejudices, and perspectives of interviewees cannot be observed without the use of an interactive interview. In interpretivism, a single phenomenon may have multiple interpretations (Pham, 2018; Kelliher, 2011). The diversifying perspectives that interpretivism brings into a phenomenon enable the eliciting of authentic information relating to the unit of analysis (Leitch et al., 2010; Basden, 2011). Through the use of qualitative methods, such as interviews, interpretivism enables a deeper understanding of a complex phenomenon (Carcary, 2011; Williams, 2000). This means that it focuses on the meaning of the research data, and is associated with the use of multiple research methods (diverse approaches) to reflect the complexities of the research question.

It also means that interpretivism is a research philosophy that deals with data interpretation and understanding. Wynn and Williams (2012) noted that interpretivism is associated with primary data of high reliability and validity. This suggests that interpretivism is well-suited for investigating hidden explanations behind complex and multidimensional phenomena, and also allows the use of observational skills, personal insights, knowledge, and the researcher's ability to extract correct information as a research instrument. The implication of this is that the interpretation and understanding that are derived from interpretivism will generate a knowledge that is bounded by time, context, culture, and value. Also, the perspectives that interpretivism bring to research will include careful consideration of the research problem and questions, provision of alternative explanations for the research constructs, and ethical consideration of the data interpretation (Doyle et al., 2009; Mabry, 2008; Idowu, 2016; Khan, 2014).

Subjectivism supports qualitative research using interviews, emphasizes the significance of data interpretation and personal perspectives (White, 2007; Hanly, 2014; Lemke, 2017), and guides hypothesis formulation, methodology selection, and data interpretation (Raddon, 2010; Sobel, 2009). As a paradigm, it explains that every respondent is a subject with a unique subjectivity, which is dependent on their perceptions, experiences, and understanding of the phenomenon under study (Bleiker et al., 2019). This means that subjectivism enables the grasping of the perspectives of the respondents through their experiences.

The dominating paradigm in this research was PRAGMATISM (see Figure 4.1). This was informed by the nature of the field of research – construction management. According to Zou et al. (2014), the use of mixed methods will greatly benefit research works in construction management because construction management is a field that combines social and natural sciences. Zou et al. (2014) reviewed the research designs of construction management by five highly ranked journals. The study found that most construction management papers used quantitative research methods, while very few papers used mixed methods or qualitative research methods. The study recommended the use of a conceptual framework as a point of departure for construction management papers. It was posited in the study that validating a conceptual framework with a mixed-method approach will greatly enable the integration of theory and practice in construction management.

Similar studies have also supported the use of mixed methods for construction management research. For example, Holt and Goulding (2014) conducted a detailed study of the use of mixed-methods research in the field of construction management. The study conceptualized and proposed ambiguous mixed methods research as a new research design for construction management research methodology. Runeson (1997) commented on the role of theory in construction management research. The study concluded that positivist research methods are the best way to reduce subjectivity and also serve as the best insurance against bad research in the field of construction management. Panas and Pantouvaku (2010) evaluated the research methodology in construction management studies. The study concluded that linking different methodological aspects within an integrated research design will contribute towards overcoming both the expected and subtle difficulties of conducting valid research in the field of construction management. Holt and Goulding (2017) explored the ontological, epistemological, and paradigmatic approaches to construction management research. The study found that there is inconsistent use of ontology, epistemology, and paradigm in construction management research, and called for greater recognition of these philosophical disciplines in research design for construction management research.

The research approach deals with processes employed in studying the phenomenon under study. A positivist research approach was adopted for this research. This approach supported the scientific and statistical verification of BIM implementation, adoption, and collaboration among the direct participants of BBCPs. Based on the philosophical position and orientation of the research (see Figure 4.1), a quantitatively driven mixed-methods research design was adopted (that is, a sequential explanatory mixed-methods). The choice of a quantitatively driven mixed-methods research design (see Figure 4.1) was informed by the research question of this study. The research question investigated the BIM implementation strategies that will result in sustained BIM adoption practices and the best levels of integration and collaboration among the BIM supply chain members. The research question investigated in this study required a deeper understanding of the phenomenon under study. As noted in the research problem, this research aimed to examine the barriers to BIM adoption on construction projects and whether there are specific BIM implementation strategies that will bring about sustained BIM adoption practices and the best levels of integration and collaboration among the BIM supply chain members. As a result, there is a need for a philosophical orientation and position that will enable the understanding of BIM implementation process and stages and the development of theories on BIM implementation.

4.3 Research design

This research employed a quantitatively driven mixed-methods design. The sequential explanatory design of the mixed methods, priority of the research design, and representation of the research variables are discussed in the subsequent sub-sections.

4.3.1 Quantitatively driven mixed-methods (sequential explanatory mixed methods)

A quantitatively driven mixed-methods research design was employed for this research. The choice of the design enabled the investigation of BIM implementation in its natural settings and also allowed an analytical and theoretical generalization. As a research design, a mixed method offers unique methodological advantages for addressing research questions (Malina et al., 2011; Johnson and Onwuegbuzie, 2004; Palinkas et al., 2015; Palinkas et al., 2011). Abowitz and Toole (2010) and Östlund et al. (2011) described mixed-method research as a research procedure for collecting, analysing, and integrating both qualitative and quantitative data collection methods within a single study. Leonard and Odutola (2016) and Morse (2010) highlighted that a mixed-method design is useful for gaining a better understanding of the phenomenon under study, for capturing the details of the phenomenon, for getting sufficient and balanced information, and for an in-depth exploration of a complex phenomenon.

Likewise, Östlund et al. (2011) and Zohrabi (2013) maintained that mixed-method design is useful for studying unique cases from multiple perspectives and for collecting detailed information through the use of a variety of data collection method. This confirmed that a mixed-method is a robust research design where qualitative and quantitative data collection methods complement each other through their strengths and the elimination of each other's shortcomings (Manzoor, 2020; Noor, 2008; Crowe et al., 2011; Widdowson, 2011; Snyder, 2012). The considerations guiding the use of a mixed-method design include the theoretical perspectives, the research paradigm, the degree of complexity of the phenomenon under study, and the purpose of mixing the research methods (Johnson and Onwuegbuzie, 2004; Palinkas et al., 2015; Crowe et al., 2011).

In this research, the phenomenon under study was BIM implementation, which is a multi-dimensional phenomenon, and the theoretical perspectives employed provided multi-dimensional perspectives, the research paradigm employed supported the use of mixed methods, and the purpose of mixing the research methods was to heighten the validity and reliability of the knowledge and theories that will emanate from the research. All these rationales justified the use of a mixed-method design in this research.

4.3.2 Sequential explanatory design

Sequential explanatory design, as a system of designing mixed-method studies, produces a type of mixed method where qualitative and quantitative data are collected and analysed consecutively (Ivankova et al., 2006; Fetters et al., 2013). It is a reliable and rigorous research design in that the qualitative data explain and refine the general understanding that quantitative data provide (Subedi, 2016; Creswell et al., 2008). This implies that quantitative data are collected and analysed before the collection and analysis of the qualitative data. The reason for this is the need to use the qualitative data to elaborate on and explain hidden details in the quantitative data. In accordance with the provisions of sequential explanatory design, this research employed quantitative method to achieve all the five research objectives; while qualitative method was employed to elaborate on the quantitative data collected for the five research objectives. Sequential explanatory design becomes useful most especially where unexpected results will arise from quantitative data, and where it is required to explore quantitative data in detail (Creswell and Clark, 2017). The point at which both the quantitative and qualitative data are connected depends on the priority of the research design (Terrell, 2012). Figure 4.2 illustrates the research design showing the point of connection between the research methods.

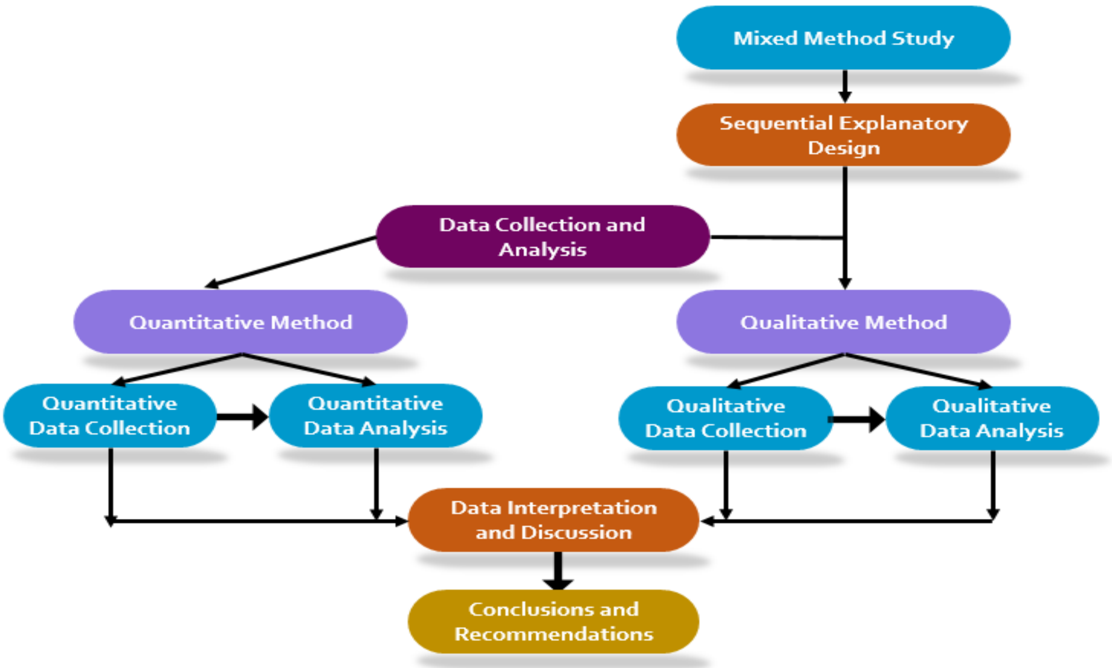

Figure 4.2: Flowchart for the research design

4.3.3 Priority of the research design

Priority is a substantial consideration in a sequential explanatory design because it determines the weight of the attention given to the data collected and analysed through qualitative methods (Kroll and Neri, 2009; Castro et al., 2010; Dey, 2003). Priority also determines the stage at which the qualitative and quantitative data are integrated (Onwuegbuzie and Byers, 2014; Albright et al., 2013; Onwuegbuzie and Collins, 2007; Ivankova et al., 2006). The priority of this research design was based on the sequence of data collection and analysis. In this research design, quantitative data were obtained from the respondents followed by qualitative data collection from purposively selected respondents. This shows that quantitative data was the primary data collection and analysis method. Therefore, the quantitative data was given more weight in this research in comparison to the qualitative data collection and analysis method. Based on the selected priority of the research design, the integration of the qualitative and quantitative data in this research occurred at the data interpretation and discussion stage.

4.4 Population and sample

The following sub-sections present information on the target and study population for the research, sampling process, selection technique, and selection criteria.

4.4.1 Target and study population

The target population in research refers to the unit of analysis for which the research findings are meant to generalize, while the study population is a subset of the target population that is accessible to the researcher and from where samples are selected (Asiamah et al., 2017; Fricker, 2012). The target population represents the main focus of the research and the entire group of people or cases, while the study population enables the limitation and characterization of the target population (Taherdoost, 2016; Martínez-Mesa et al., 2016; Bornstein et al., 2013). BIM-based construction projects (BBCPs) were the target ofthis research. However, because the identified BBCPs had been completed, the participants in the BBCPs (construction professionals and construction subcontractors) became the source of information on the BBCPs. This is in line with the explanation provided by Taherdoost (2016) and Etikan et al. (2016) that, when a research is studying a target population that is not an individual, the study population must compose of individuals that can most accurately report on the unit of analysis.

Therefore, the target population for this research consisted of BBCPs in South Africa, while the study population for this research consisted of BBCPs direct participants in the South African construction industry. BBCPs direct participants were taken as the study population that will represent the BBCPs because they were familiar with BBCPs and were qualified to give accurate and reliable information about the BBCPs as a result of their direct observations and participation in BBCPs. For this research, BBCPs referred to construction projects in which BIM tools, BIM software technologies, BIM principles, and/or BIM processes were employed by construction professionals and construction subcontractors to perform their roles in the delivery of the project. BBCPs were identified by visiting the cidb websites for project databases, checking the postings of BIM experts on Linked-In™, checking the postings of the members of South African BIM clubs, visiting the websites of construction organisations (general contractors and subcontractors) listed in the cidb database to identify the self-reported BBCPs in which the construction organisations had participated, and visiting construction news and innovation websites.

A total of 232 BBCPs were identified and used to determine the study population as presented in Table 4.1.

Table 4.1: Sample frame and sample size for the study

Target population	**Study population**	**Sub-groups of BBCPs' direct participants**	**Estimated study population**	**Study population based on the available e-mail contacts**	**Study population based on willingness and availability to participate**	**Sample size**
BBCPs	BBCPs' direct participants	1. Architect	232 @ 14 = 3,248	2,345	1,871	1,871@ 52%
		2. Structural/civil engineer				
		3. Mechanical engineer				
		4. Electrical engineer				
		5. Town planner				
		6. Quantity surveyor				
		7. Facilities manager				
		8. Main contractor				
		9. BIM Manager/Project manager				
		10. Steelwork subcontractor				
		11. Ductwork subcontractor				
		12. Curtain wall subcontractor				
		13. Precast products supplier				
		14. Flooring specialist				
232		14	3,248	2,345	1,871	975

As shown in Table 4.1, the study population was determined in three stages of study population based on estimation, study population based on the available e-mail contacts of the BBCPs direct participants, and study population based on the number of BBCPs' direct participants that replied and consented to the invitation letter. The study population based on estimation was determined using *Equation 4.1*.

$$Study\ population\ = A \times Bx_i^n \qquad \textbf{\textit{Equation 4.1}}$$

Where; *A = number of reported or identified BIM-based construction projects, B = sub-groups of direct participants in BIM-based construction projects, n = number of direct participants in BIM-based construction projects.*

4.4.2 Sampling and selection technique

Sampling and selection techniques refer to the process of selecting the participants for the formation of the sample size (Albuquerque et al., 2014; Alvi, 2016). The selected participants from the study population represent the study sample, while the list of all the participants available in the study population and from which the sample size is drawn represents the sampling frame (Ishak et al., 2014). A multilevel mixed-methods sampling technique was employed for this research after the guidelines outlined in Teddlie and Yu (2007). Multilevel mixed-methods sampling is a method of creating a sample size from a large study population. Multilevel mixed-methods sampling consists of a multi-stage and multi-phase level (Collins et al., 2006; Collins et al., 2007; De Lisle, 2011). At multi-stage, the sample units for creating the sample size are selected in stages and sample units are taken from the groups into which the study population is divided. In this research, the study population was purposively divided into fourteen groups. The multi-stage level was adopted for quantitative data collection, while the multi-phase level was applied to qualitative data collection. For the multi-phase level, the sample size that was created for the quantitative data collection was retained for the first phase. In the second phase, fewer samples were selected from the sample size using a selective expert sampling technique.

The first level of the sampling process was the identification of the BBCPs as the target population for this research (purposive sampling). Purposive sampling is a method of determining the study population or the sample size by choosing research participants based on pre-determined criteria or characteristics (Lopez and Whitehead, 2013; Moser and Korstjens, 2018). Purposive sampling enables the selection of participants that can provide insights into an event or phenomenon, the selection of participants with shared characteristics, the examination of past projects or experiences, the creation of significant samples that fit the profile of the study population, and the collection of reliable and detailed information from the research participants (Kim et al., 2017; Grossoehme, 2014). Purposive sampling was useful in this research for indirect case sampling of BBCPs through the construction professionals and subcontractors. The criteria for selecting the research participants that constituted the sample size for the collection of qualitative data for this research was the direct participation in BBCPs as determined by the authoring of building information models, participation in building information models review meetings, BIM knowledge, and participation in BIM-enabled collaboration.

The second level of the sampling process was achieved by identifying and dividing the study population into sub-groups (stratified sampling). The groups comprised of the fourteen major BIM supply chain members as identified by Succar (2009). Only 52% of the study population was considered in order to obtain a representative sample. Hence, the sample size for the study was 975 (see Table 4.1).

4.4.3 Selection technique and criteria for selection

The selection of the research participants for quantitative data collection was done using a random selection technique. The use of a random selection technique enables the selection of samples within each sub-group so that sufficient representativeness is guaranteed for all the identified population sub-groups. The selection of the research participants for qualitative data collection was done using selective expert sampling. Selective expert sampling is a variant of purposive sampling that enables the capturing of special knowledge, information, insights, or expertise (Moser and Korstjens, 2018; Attia et al., 2019).

The use of selective expert sampling increases the validity, reliability, and accuracy of the research findings (Juszczak and Duin, 2003; Etikan et al., 2016). It gives preference to the experts when selecting samples from the study population (Libakova and Sertakova, 2015). The study population for this research comprised of groups such as *Architect, Structural/Civil engineer, Mechanical engineer, Electrical engineer, Town planner, Quantity surveyor, Facilities manager, Main contractor, BIM Manager/Project manager, Steelwork* *subcontractor, Ductwork subcontractor, Curtainwall subcontractor, Precast products supplier,* and *Flooring specialist.*

The criteria for selecting the experts among the groups of construction professionals and subcontractors contained in the study population included having BIM-related training and qualifications, having superior BIM-related skills, and having first-hand information on BIM adoption and implementation on projects. BIM managers are the experts that were selected for the qualitative data collection (interview) in this research because their views and opinions are superior to those of other groups in the study population, they are more knowledgeable in BIM processes and tools, and they have BIM-related experience and training to qualify as BIM managers. The choice of the BIM managers was informed by the needs of the research design and priority. The research was designed to employ an interview for a deeper exploration of quantitative data. BIM managers qualified as experts to provide deeper insights into BIM implementation and the mechanism of BBCPs. The experience and superior knowledge of BIM managers were essential to this research because BIM managers are construction professionals with practical and deeper knowledge of BIM adoption on projects.

4.5 Research methods

The questionnaire survey was the primary data collection tool for this research, together with the interview. The process of designing the questionnaire survey, the process of designing the interview, methods of data collection, and duration of data collection are presented in the following sub-sections.

4.5.1 Questionnaire design

Questionnaire design is the process of constructing the questions and format of the survey instrument (questionnaire) for data collection (Dörnyei and Taguchi, 2009; Burgess, 2001; Acharya, 2010; Artino et al., 2014). The objective of the questionnaire design is to ensure the collection of standardized data and reduce the amount of standard error in data analysis (Morrison et al., 2010; Brace, 2018; Rattray and Jones, 2007). The survey instrument for this research consisted of a set of written questions with a number of possible answer. The importance of each question contained in the questionnaire was determined based on the contribution of each question to the research objectives, the need for cross-checking of answers, the need to obtain non-ambiguous answers, and the need to elicit correct and relevant information.

The survey instrument was broken down into five (5) sections with a total of twenty-two (22) questions. The first section of the instrument focused on general questions related to the participants' characteristics, firms' characteristics, and the characteristics of the BIM-based construction projects (BBCPs). The questions that addressed the characteristics of the BBCPs were project-specific and focused on descriptive information for a BBCP selected by the participants. The following information was collected: project category, project client, project duration, project team size, project milestones and deadline, construction systems employed, project sensitivity, LOD, procurement system, BIM tools employed, BIM principles employed, BIM capacity employed, and BIM performance assessment methods that were used to characterize the BBCPs. The second section of the questionnaire focused on the levels of integration and collaboration that occurred among the organisations and team members that participated in the BBCPs.

The questions in this section required the participants to evaluate the occurrence of trust-based relationships, information sharing and exchange, network communication, and knowledge sharing and transfer among the project participants as a result of BIM adoption on the projects. Section three concentrated on the BIM implementation strategies in use in the South African construction industry. In this section, participants were asked to rate the commitment strategies used by the top management of their organisations towards ensuring the adoption of BIM on the BBCPs they participated in, and the motivations for BIM adoption on projects as provided by the construction industry leaders and stakeholders, the strategies in use by their organisations for developing the capacity of their employees to use BIM tools and technologies on construction projects. Finally, the participants were asked to indicate their level of agreement with statements describing approaches to strategic BIM adoption on construction projects using a Likert scale. Sections four and five presented questions on the challenges that were encountered in BIM adoption on projects, the challenges that would prevent the adoption of BIM on their future construction projects, and the indicators of a reduction in barriers to BIM adoption on construction projects. The final section of the questionnaire survey (section six) covered the perspectives of the participants on the BIM implementation strategies that would ensure the widespread adoption of BIM on construction projects, construction organisations, and the construction industry. Table 4.2

presents a summary of the questionnaire design for this research (see Appendix C for the detailed-questionnaire).

Table 4.2: A summary of the questionnaire design for the research

Sections	Variables	Measurement scale
Characteristics of participants and company	Educational background, designation, services provided, area of expertise, location of head office, number of employees, company age, region of operation, and years of experience in the construction industry	Nominal scale
Characteristics of the BIM-based construction projects	Category of the project, type of client for the project, duration of the project, size of the project consulting team, project size, project milestones and deadlines, construction technologies and systems used for the project, political and cultural sensitivity of the project, regulatory requirements, project supply chain, level of development of the building information models, collaborative procurement process used, project team composition, modalities for sharing the cost of BIM adoption, BIM software technologies used, and BIM principles used	Nominal scale
Level of BIM adoption on the BIM-based construction projects	BIM skills and competence	5-point Likert scale: 5=experienced level, 4=specialist level, 3= expert level, 2= functional level, 1= entry level
	BIM tools	5-point Likert scale: 5=to a large extent, 4=moderate extent, 3= some extent, 2= rarely, 1= not at all
	Building information models' level of details	5-point Likert scale: 5=to a large extent, 4=moderate extent, 3= some extent, 2= rarely, 1= not at all
	Types of building information models	5-point Likert scale: 5=to a large extent, 4=moderate extent, 3= some extent, 2= rarely, 1= not at all
	BIM performance assessment criteria	5-point Likert scale: 5=to a large extent, 4=moderate extent, 3= some extent, 2= rarely, 1= not at all

Table 4.2: A summary of the questionnaire design for the research (cont'd)

Sections	**Variables**	**Measurement scale**
Levels of integration and collaboration among the BIM supply chain members	Trust-based relationships	5-point Likert scale: 5=to a large extent, 4=moderate extent, 3= some extent, 2= rarely, 1= not at all
	Information sharing and exchange	5-point Likert scale: 5=to a large extent, 4=moderate extent, 3= some extent, 2= rarely, 1= not at all
	Network communication	5-point Likert scale: 5=to a large extent, 4=moderate extent, 3= some extent, 2= rarely, 1= not at all
	Knowledge sharing and transfer	5-point Likert scale: 5=to a large extent, 4=moderate extent, 3= some extent, 2= rarely, 1= not at all
BIM implementation strategies in use in the construction industry	BIM commitment (Top management commitment strategies)	5-point Likert scale: 5=highly agree, 4=agree, 3=true to some extent, 2= disagree, 1= highly disagree
	BIM motivations (BIM motivation strategies)	5-point Likert scale: 5=highly agree, 4=agree, 3=true to some extent, 2= disagree, 1= highly disagree
	BIM capacity development	5-point Likert scale: 5=highly agree, 4=agree, 3=true to some extent, 2= disagree, 1= highly disagree
	BIM utilization	5-point Likert scale: 5=highly agree, 4=agree, 3=true to some extent, 2= disagree, 1= highly disagree
Barriers to BIM adoption on construction projects	Barriers to preliminary BIM adoption	5-point Likert scale: 5=very high, 4=high, 3=somewhat high, 2= low, 1= very low
	Barriers to sustained BIM adoption	5-point Likert scale: 5=very high, 4=high, 3=somewhat high, 2= low, 1= very low
Indicators of a reduction in barriers to BIM adoption on construction projects		5-point Likert scale: 5=highly agree, 4=agree, 3=true to some extent, 2= disagree, 1= highly disagree
BIM implementation strategies that are required for ensuring BIM adoption on construction projects	BIM commitment (Top management commitment strategies)	5-point Likert scale: 5=highly agree, 4=agree, 3=true to some extent, 2= disagree, 1= highly disagree
	BIM motivations (BIM motivation strategies)	5-point Likert scale: 5=highly agree, 4=agree, 3=true to some extent, 2= disagree, 1= highly disagree
	BIM capacity development	5-point Likert scale: 5=highly agree, 4=agree, 3=true to some extent, 2= disagree, 1= highly disagree
	BIM utilization	5-point Likert scale: 5=highly agree, 4=agree, 3=true to some extent, 2= disagree, 1= highly disagree

4.5.2 Interview design

A structured interview was adopted for qualitative data collection. The structured interview describes a type of interview where the questions are predetermined and presented to the interviewees in the same order (Kallio et al., 2016; de la Croix et al., 2018). This research adopted a structured interview because it eliminates the interviewer's bias, brings consistency in methodology and data, makes it easier to analyse the data, and enables a fair and objective evaluation. The interview questions were grouped into two sections of personal questions and questions on BIM implementation in the construction industry. The section on the personal questions covered the work responsibilities and work experiences of the interviewees. The second section presented questions on the understanding of the interviewees on the components of collaboration among the BBCPs participants, the components of BIM adoption on construction projects, the methods of BIM adoption for achieving integration and collaboration among the BBCPs participants, the appropriate BIM implementation strategies, and the barriers preventing the project organisations from experimenting with BIM on construction projects. The interviewees were further asked to give their perspectives on the barriers that could prevent the continuous use of BIM at various stages of a project and on subsequent construction projects. Appendix D shows the interview guide that was used in this research. The interview guide contains a total of twenty-one (21) questions covering the research objectives.

4.5.3 Methods and duration of data collection

A web-based survey is a method of quantitative data collection through an electronic questionnaire (Cobanoglu et al., 2001; Greenlaw and Brown-Welty, 2009). In a web-based survey, responses are provided via a web browser and are stored in web-based databases (Cole, 2005; Daley et al., 2003). A web-based survey is usually implemented on web-based survey software, such as Google Form™, SurveyMonkey™, QuestionPro™, and FluidSurveys™ (Elbeck, 2014; Duarte, 2014; Sabharwal, 2016). A web-based survey enables the creation of an attractive survey, the use of easy reminder and follow-up on non- and partial responses, a wider reach of participants, a cost-efficient and time-saving survey, a real-time data analysis, the collection of accurate and reliable data, and a timely collection of data (Baltar and Brunet, 2012; Mertler, 2002).

In this research, the web-based survey was distributed via e-mail invitation and web-link with the title *a survey on the nexus between building information modelling implementation* *strategies, adoption, and levels of the construction supply chain stakeholder integration.* The e-mail invitation and web-link were launched through the SurveyMonkey™ subscription of the *Construction Business and Management Research Group, Department of Construction Economics and Management, University of Cape Town.* No personalized and direct e-mail was sent. Sourcing for contacts (e-mail contacts, and social media contacts) was done by checking the cidb database of the e-mail contacts of construction firms, personal websites of construction firms with self-reported BBCPs, Linked-In pages, personal pages on BIM club websites, and face-to-face meetings at the BIM conference in Johannesburg. The actual data collection was carried out over thirteen (13) months (August 2018 – August 2019).

The following actions were taken to increase responses: (a) *Follow-up e-mails*, (b) *Thank You e-mails* (sent when someone completed the survey), (c) *A one-off reminder e-mail* (sent two days after the first invitation, sent to people with no response or partial response). *Question Skip Logic* was employed to enforce the participants' selection criteria. *Question Skip Logic* made it possible to skip participants to a later page, or a specific question on a later page, based on their answer to a previous closed-ended question. The logic paths employed for the *Question Skip Logic* in this research included the characteristics of the BBCPs and the BIM-specific questions. To implement the page options for *Question Skip Logic*, participants were asked to choose a specific BBCP in which they had participated and use their BIM experience to answer the survey questions. In the cases of participants, who indicated that they had not directly participated in a BBCP, the survey was designed to skip them directly to the end of the survey, and their responses were considered as COMPLETE. This was done to move respondents forward in the survey and to encourage them to complete the survey. Figure 4.3 presents the volume and pattern of the responses for the survey.

During the process of quantitative data collection and analysis, participants that identified themselves as BIM managers were contacted via an e-mail invitation to indicate their willingness to participate in an interview. Ten participants indicated their willingness to participate in the research, while only three eventually participated in the interview.

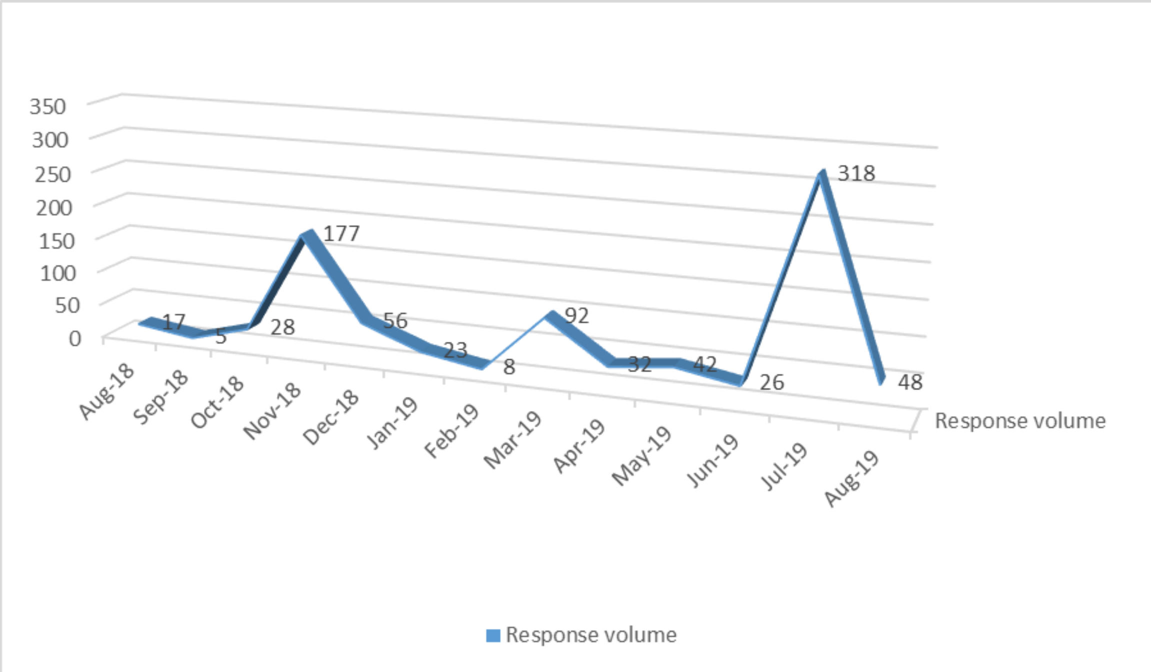

Figure 4.3: Responses volume and pattern

4.6 Methods of data analysis

Data analysis was carried out in two parts. The first part dealt with the analysis of the quantitative data (analysis of the measurement models and analysis of the structural models). The second part covered the analysis of the qualitative data.

4.6.1 Analysis of the measurement models (reliability and validity tests)

This section presents the analysis methods that were used to test the reliability and validity of the measured variables. These analysis methods are discussed in the following sub-sections.

4.6.1.1 Mean item score

The mean item score is the average of the research participants' summated score divided by the number of measured variables constituting the Likert scale (Cummins and Gullone, 2000; Leung, 2011). The mean item score was used in this research as one of the reliability and validity tests for the measurement models (that is, as the test of significance for the measured variables). SPSS (version 26) was used to compute the mean item score for the measured variables in this research. Equation 4.2 describes the mathematical definition of the mean item score. Table 4.3 presents the cut-off value for determining the significance of the measured variables based on their mean item score.

$$Mean\ item\ score = \frac{1_{n_1} + 2_{n_2} + 3_{n_3} + 4_4 + 5_{n_5}}{N} \qquad \textit{Equation 4.2}$$

Where; *N = total respondents, n_1 = number of participants indicating 1 on the Likert scale, n_2 = number of participants indicating 2 on the Likert scale, n_3 = number of participants indicating 3 on the Likert scale, n_4 = number of participants indicating 4 on the Likert scale, n_5 = number of participants indicating 5 on the Likert scale.*

Table 4.3: Cut-off value for mean item score

Score range	The point on the Likert scale	Cut-off value	References
1.00 – 1.80	1	2.61: low significance	Maree and Pietersen, 2007; Boone and Boone, 2012; Joshi et al., 2015
1.81 – 2.60	2		
2.61 – 3.40	3	3.41: high significance	
3.41 – 4.20	4		
4.21 – 5.00	5		

4.6.1.2 Confirmatory factor analysis

Confirmatory factor analysis is a confirmatory test of the validity of the measurement models (Marsh et al., 2014; Graham et al., 2003). It establishes the convergent and discriminant validity and reliability of the measured variables (Schreiber et al., 2006; Thompson, 2004), as well as confirms the predetermined internal structure of the set of measured variables (Suhr, 2006; Harrington, 2009). This research used confirmatory factor analysis to confirm if the measured variables were consistent with the nature of the theoretical constructs. Principal Components Analysis was used as the extraction method and the Varimax (orthogonal rotation method) was used as the rotation method. The mathematical equation of confirmatory factor analysis (CFA) is presented in Equation 4.3; while the criteria for determining the validity and reliability of the measured variables based on the confirmatory factor analysis are shown in Table 4.4.

As explained in Table 4.4, factor loading, Eigenvalue, correlation coefficient, KMO value, Bartlett's test results, and Average Variance Explained (AVE) were the CFA results that were used in this research to confirm the validity and reliability of the measured variables. The analysis was performed on SPSS (version 26). Factor loading is the product-moment correlation coefficients between the constructs and the measured variables (Bandalos and Finney, 2018; Pison et al., 2003). It indicates a measure of the correlation of the measured variables to the constructs (Asparouhov and Muthén, 2014; Costello and Osborne, 2005). Eigenvalues represent the variances of the measured variables (Larsen and Warne, 2010; Hayton et al., 2004). This means that it measures how much of the variance of the measured variables that the constructs explain. The correlation coefficient shows the strength of the relationship between the measured variables (Mukaka, 2012; Bewick et al., 2003). KMO value is a measure of sampling adequacy and it indicates that the proportion of variance in the measured variables is caused by certain constructs (Peri, 2012; Yong and Pearce, 2013). The results of Bartlett's test help to determine if there is a valid internal structure in the measured variables (that is, if the measured variables are related). AVE measures convergent validity by showing the amount of variance in measured variables that was explained by a construct (Bandalos and Finney, 2018; Taherdoost et al., 2014).

$$Xj = a_{j1}f_1 + a_{j2}f_2 + a_{j3}f_3 + a_{j4}f_4 + \cdots a_{jm}f_m + ej \qquad \textbf{\textit{Equation 4.3}}$$

Where; *j=1, 2, 3……, p=number of variables* ($X_1, X_2 \ldots X_p$)*, m=number of underlying components/factors* ($f_1, f_2 \ldots f_m$)*,* $a_{j1}, a_{j2} \ldots a_{jm}$*= factor loading*

Table 4.4: Cut-off value for Confirmatory Factor Analysis values

Criteria for validity and reliability	Indication	Cut-off value	References
Factor loading	A measure of the correlation of the measured variables to the constructs	> 0.70	Hair et al., 2010; Levine, 2005; Zou et al., 2003; Asuero et al., 2006; Weir, 2005; Trujillo-Ortiz et al., 2006; Lloret et al., 2017; Beavers et al., 2013
Eigenvalue	A measure of the amount of variance accounted for by each of the measured variables	>1.00	
Correlation coefficient	A measure of discriminant validity	>0.60	
KMO value	A measure of sampling adequacy	≥0.6	
Bartlett's test	Test of sphericity	Significance value must be less than 0.05	
Average variance explained	A measure of convergent validity	>0.5	

4.6.1.3 Cronbach's alpha coefficient

Cronbach's alpha coefficient is an estimate of the reliability of the measured variables (Christmann and Van Aelst, 2006; Sijtsma, 2009). It estimates the internal consistency of measured variables on the Likert scale (Shevlin et al., 2000). The internal consistency describes the extent to which there is cohesiveness among the responses by the research participants to the measured variables (Helms et al., 2006; Streiner, 2003). The Cronbach's alpha values for the measured variables in this research were computed using SPSS (version 26). The mathematical definition of Cronbach's alpha coefficient is presented in Equation 4.4. The interpretation and cut-off value used in determining the internal consistency of the measured variables as explained by their Cronbach's alpha coefficients are shown in Table 4.5.

$$Cronbach's\ alpha = \frac{n}{n-1}\left|1 - \frac{variance_{error}}{variance_{observed}}\right| \qquad \textbf{\textit{Equation 4.4}}$$

Where; n = *number of measured variables*

Table 4.5: Cut-off value for Confirmatory Factor Analysis values

Range	Interpretation	Cut-off value	References
α≥0.9	Excellent reliability	≥0.90	Gliem and Gliem, 2003; Taber, 2018; Tavakol and Dennick, 2011; Peters, 2018; Eisinga et al., 2013
0.9>α≥0.8	Good reliability		
0.8>α≥0.7	Acceptable reliability		
0.7>α≥0.6	Questionable reliability		
0.6>α≥0.5	Poor reliability		
0.5>α	Unacceptable reliability		

4.6.2 Analysis of the structural models

In the following sub-sections, the method of estimating model parameters and evaluating the goodness of fit of the models are discussed.

4.6.2.1 Maximum Likelihood Estimation

Maximum Likelihood Estimation (MLE) is a method of estimating model parameters in Structural Equation Modelling (SEM) (Zhong and Yuan, 2011; Yuan et al., 2000; Iacobucci, 2009). MLE serves as the path significance test for the structural equations (models) (Pan and Fang, 2002; Wooldridge, 2014). Yuan and Chan (2008) and Kyriazos (2018) describe MLE as an unbiased model estimation method that is suitable for a large sample size. Yuan and Bentler (2007) described MLE as the most predominant and reliable SEM method. Also, Palomo et al. (2007) described an SEM method that provides numerical stability, greater efficiency, and estimates that are not affected by sampling error and consistent estimates. This implies that the likelihood functions generated by MLE are useful in testing hypotheses about models. Also, it means that the parameter estimates provided by MLE maximize the likelihood function (that is, provide the greatest probability) for a model.

MLE estimates the mode (structural equations) parameters by minimizing the incongruity between the structural equations and the obtained covariance (Daigle et al., 2012). The model parameters that were estimated for the structural models in this research are explained in

Table 4.5. The parameter estimates of a model define the conformity of its structural equations to the empirical data (Enders and Bandalos, 2001; Kuhn and Lavielle, 2005). The SEM using the MLE method was done in this research using ONYX (version 3.7.9). Table 4.6 explains the cut-off values for the parameter estimates in the structural equation models.

Table 4.6: Cut-off value for the parameter estimates in the structural equation model

Parameter estimates	Range and interpretation	Cut-off value	References
z-value	<1.96 – Not significant >1.96 – Significant	>1.96	Yuan et al., 2011; Kyriazos, 2018; Lai, 2018; Tarka, 2018
r-value	<0.05 – Not significant >0.05 – Significant	>0.05	

4.6.2.2 Fit evaluation for the model

Fit evaluation enables the analysis of the goodness of fit measures for hypothesized models to provide useful information about the hypothesized model (Haslinger et al., 2010; Hooper et al., 2008; Moshagen, 2012). The fit evaluation for the structural equations (models) in this research was determined using Chi-square goodness of fit test, Standardised Root Mean Square Residual (SRMR) index, comparative fit index (CFI), Root Mean Square Error of Approximation (RMSEA) index, and Tucker-Lewis (TLI) index. It is important to use multiple fit indexes because a single fit index cannot be relied upon as a basis for determining the goodness of fit of a model (Taasoobshirazi and Wang, 2016; Barrett, 2007; Schermelleh-Engel et al., 2003; Moshagen, 2012). The Chi-square goodness of fit test gives a fit index that shows how well a hypothesized model fits into observed data (Mačutek and Wimmer, 2013; Satorra and Bentler, 2010). The test evaluates the hypothesized model against the observed data by evaluating the scale of incongruity between the fitted and sample covariance matrix as presented in Equation 4.5.

SRMR index evaluates the goodness of fit of the hypothesized model by determining the average square root of the residual between the model-specified covariance matrix and the observed covariance matrix (Sivo et al., 2006; Asparouhov and Muthén, 2018). This means that the SRMR index shows the standardized differences between the predicted correlation and observed correlation (see Equation 4.6). CFI measures the relative improvement in the goodness of fit of a hypothesized model from the baseline model to the hypothesized model. It tests the goodness of fit of a hypothesized model by assuming that all constructs (latent variables) are un-associated and compares the sample covariance matrix with the constructs (Lai and Green, 2016; Savalei, 2018).

In CFI, the uncorrelated constructs represent the hypothesized model (see Equation 4.7). RMSEA measures the discrepancy in the hypothesized model per degree of freedom (Steiger, 2000; Brosseau-Liard et al., 2012; Kenny et al., 2015). It evaluates the model complexity by uniting a degree of freedom in the construction of the model (see Equation 4.8). TLI measures the goodness of fit of a hypothesized model by evaluating the difference between the Chi-square value for the null model and the target model (see Equation 4.9). The indications and cut-off values for the fit indexes as adopted in this research are presented in Table 4.7.

$$x^2 = (N-1)f \qquad \textbf{\textit{Equation 4.5}}$$

Where; x^2 = *chi-square value, f = minimized discrepancy function, N = sample size*

$$SRMR = [P^{*-1}(e'W_s e)]^{1/2} \qquad \textbf{\textit{Equation 4.6}}$$

Where; *P^* = non-redundant elements in the observed covariance matrix, e = a vector of residuals from a covariance matrix, W_s = a diagonal matrix used to standardize the elements in a sample covariance matrix*

$$CFI = \frac{max(x_o^2 - df_o, o) - max(x_k^2 - df_k, o)}{max(x_o^2 - df_o, o)} \qquad \textbf{\textit{Equation 4.7}}$$

Where; *o = baseline model, k = hypothesized model, d_f = degree of freedom*

$$RMSEA = \sqrt{\frac{\lambda_N}{df}} = \sqrt{\frac{max(x^2 - df_o)}{df(N-1)}} \qquad \textbf{\textit{Equation 4.8}}$$

Where; *λ_N = non-centrality parameter*

$$TLI = \frac{\frac{x_o^2}{df_o} - \frac{x_k^2}{df_k}}{x_o^2/df_o - 1} \qquad \textbf{\textit{Equation 4.9}}$$

Where; *o = baseline model, k = hypothesized model, d_f = degree of freedom*

Table 4.7: Cut-off value for the goodness of fit indexes

Fit indexes	Indications	Cut-off value	References
Chi-square goodness of fit test	A measure of absolute fit for models	The value of the chi-square test must be insignificant	Cangul, 2015; Nye and Drasgow, 2011; Singh, 2009; Moshagen, 2012; Bryant and Satorra 2012; Taasoobshirazi and Wang, 2016; Sivo et al., 2006; Xia and Yang, 2019
SRMR index	A measure of absolute fit for models	≤0.10	
Comparative fit index	A measure of relative fit for models	≥0.97	
RMSEA index	A measure of absolute fit for models	≤0.08	
Tucker-Lewis index	A measure of the relative for models	≥0.97	

4.6.3 Data analysis methods for the qualitative data

The methods of analysing the qualitative data are discussed in the subsequent sub-sections.

4.6.3.1 Thematic analysis

Thematic analysis (TA) is a qualitative analysis method that examines and pinpoints themes within qualitative data (Braun and Clarke, 2006; Braun and Clarke, 2012; Clarke et al., 2015). TA is useful for summarizing a large data set, highlighting differences and similarities across the dataset, conceptualizing patterned meaning in the dataset, capturing recurring patterns across a dataset, and producing insightful and trustworthy findings (Joffe, 2012). In TA, themes are usually identified inductively or deductively. In the induction approach, themes are identified from the raw data based on the insights and description provided by the participants (Vaismoradi et al., 2013; Vaismoradi et al., 2016). In the deduction approach, themes are identified from the theoretical framework adopted for the research (Braun et al., 2019).

Themes that are identified in thematic analysis refer to the collective description, insights, or explanation of a phenomenon (Alhojailan, 2012; Guest et al., 2012). TA can be done manually or using Computer-Aided Thematic Analysis (CATA). CATA is useful for the dataset from a large number of participants because it speeds up the analysis process (Kabay, 2003; Friese et al., 2018). However, unlike the manual approach, CATA limits the integrity, intelligence, intuition, and insights that a researcher brings to TA (Kabay, 2003). In this research, the TA of the interview transcripts was done manually using an induction approach according to the procedures outlined by Braun and Clarke (2012). Each interview question was analysed separately. Responses provided by the participants (interviewees) for the interview questions were compared, to identify collective descriptions, insights, or explanations.

4.7 Research ethics

Research ethics describe the guidelines for conducting responsible research (Guillemin and Gillam, 2004). Research ethics are essential to establishing research credibility, validity, and authenticity (Benatar, 2002). This is low-risk research because it elicits information only from construction professionals and construction subcontractors, who confirmed their participation in BBCPs. The information was elicited in an anonymous manner and with respect for privacy and human dignity. The research instruments were designed to respect the anonymity of the research participants by not capturing their details. The research instruments for this research were submitted to the University of Cape Town (UCT) Research Ethics Committees for approval as presented inAppendix H. The approval for the research instruments was granted after the Ethics Committee had scrutinized the research instruments and confirmed their conformance with UCT's ethical norms and standards in research. The information elicited from the participants was presented without falsification, distortion, and partiality.

4.8 Summary of research philosophy and methodology

This chapter gives details on the philosophical foundation (orientation and position) underpinning the research design for this study. The chapter clarified the ontological position, epistemological position, methodological approach, and research approach that were adopted for this study. The epistemological position of this research emphasized empirical evidence as essential to understanding BIM implementation, adoption, and collaboration among the direct participants of BIM-based construction projects. The research approach was POSITIVISM while the dominating research paradigm was PRAGMATISM. A quantitatively driven mixed-methods research design was adopted based on the philosophical position and orientation of the research. Also, the chapter discussed the target and study populations for the research, sampling process, selection technique, selection criteria, questionnaire design process, interview design process, duration of data collection, methods of data collection, and methods of data analysis.

CHAPTER FIVE

DATA ANALYSIS AND RESULTS

5.1 Introduction

This chapter presents the analysis of the profile of research participants, the mean item score analysis of quantitative data, and the thematic analysis of the qualitative data. The profile of the research participants includes demographics – such as the educational background of the respondents – services provided, area of expertise, and years of experience in the construction industry. The mean item score analysis includes the mean item score of the BIM implementation strategies that are employed in order to drive BIM adoption on construction projects, the indicators of a reduction of barriers that prevent preliminary and sustained BIM adoption on construction projects, the level of BIM adoption on construction projects, and the levels of integration and collaboration among the BIM supply chain members.

5.2 Profile of research participants

The profile of research participants for the quantitative part of the research, profile of the construction organisation where the respondents were employed, and the profile of interviewees for the qualitative part of the research were analysed using frequency distribution and percentage. Out of the 975 expected questionnaires, only 872 questionnaires without a substantial amount of missing and incomplete data were completed by the respondents. This gives a response rate of 89%. The profile of respondents for the quantitative part of the research includes key demographics, such as the educational background of the respondents, services provided, area of expertise, and years of experience in the construction industry. Table 5.1 shows that 35.17% of the research participants have *a Diploma with Grade 12*. Only 25.13% of the research participants have a *Diploma with less than Grade 12 (N4-6/N7C4-6).* Other notable academic qualifications of the research participants include *Bachelor's Degree* (22.49%), *Higher Diploma* (18.4%), and *a Master's Degree* (10.84%).

Most of the research participants are in *Director Cadre* (72.21%). The remaining responses were from research participants in the *Management Cadre* (19.09%), and *Technical Officer* (8.69%). The distribution of services provided by the research participants includes *Main Contractor* (23.12%), *Subcontractor* (7.58%), *Supplier* (16.39%), *Construction Manager*

(13.35%), *Project Manager* (10.74%), *Consultants* (10.42%), *Developer* (3.36%), *and Specialist* (3.36%), and BIM manager (1.62%).

Table 5.1: Profile of respondents

Answer Choices	**Response Percent**	**Response number**
Educational background of the research participants		
Certificate-Diploma with Grade 12	35.17%	172
Bachelor's Degree	22.49%	110
Higher Diploma [Technicon/University of Tech]	18.4%	90
N4-6/NTC4-6/Certificate-diploma with less than Grade 12	15.13%	74
Master’s Degree	10.84%	53
PhD	1.02%	5
Designation of research participants		
Director Cadre	72.21%	382
Management Cadre	19.09%	101
Technical Officer	8.69%	46
Services provided		
Main Contractor	23.12%	213
Subcontractor	17.58%	162
Supplier	16.39%	151
Construction Manager	13.35%	123
Project Manager	10.74%	99
Consultants	10.42%	96
Developer/Client	3.36%	31
Specialist	3.36%	31
BIM Manager	1.62%	15
Area of Expertise		
Building and civil engineering construction	48.96%	260
Building construction	44.63%	237
Civil engineering	25.42%	135
Special construction/ special works	11.49%	61
Mechanical engineering works for infrastructure	7.72%	41
Electrical engineering works for building	7.16%	38
Mechanical engineering works for building	6.97%	37
Electrical engineering works for infrastructure	6.78%	36
Years of experience in the construction industry		
11 – 15 years	70.73%	576
16 – 20 years	18.77%	152
21 years and above	10.50%	86

With regard to the area of expertise, 48.96% specialise in building and civil engineering construction, 44.63% specialise in building construction, and 25.42% are specialists in civil engineering. Other notable areas of expertise include special construction (11.49%), mechanical engineering works for infrastructure (7.72%), electrical engineering works for building (7.16%), mechanical engineering works for building (6.97%), and electrical engineering works for infrastructure (6.78%).

As concerns the participants’ years of experience in the construction industry, most of the respondents (70.73%) have 11-15 years of experience. Only 10.50% of the research participants have had more than 21 years' experience, while 18.77% have had 16-20 years of experience. The result of the analysis of demographics of the research participants for the quantitative part of this research suggests that the information provided by the research participants will be a useful, legitimate, and authentic representative of the various views in the construction industry.

Table 5.2 shows the key demographics for the construction organisation where the research participants were employed, which include the location of the head office, number of employees, company age, and region of operation. In terms of head office location, most of the construction organisations are located in Kwa-Zulu Natal (31.6%). This is closely followed by Gauteng (19.39%), the Eastern Cape (16.34%), and the Western Cape (13.29%). Only 6.46% of construction organisations have their head offices located in Limpopo. Others have their head offices in the Free State (5.75%), Mpumalanga (5.75%), Northern Cape (5.21%), and North-West (4.67%). As regards the number of employees, 87.05% of the construction organisations employ less than 50 people, while 7.13% have 51-200 employees, and 5.82% have more than 200 employees.

Regarding the company age, construction organisations with six to ten years of existence accounted for 34.96% of the distribution, while construction organisations with less than five years of existence accounted for 24.96% of the distribution. Construction organisations with a company age above 10 years accounted for 19.79% (11-15 years), 13.01% (21 years and above), and 8.02% (16-20 years) of the distribution. As regards the region of operation of the construction organisations, most of the construction organisations operate at the provincial level (40.97%), local level (34.88%), and national level (28.8%). Other regions of operation for the construction organisations include regional level (13.42%) and international level (8.77%). The results of the analysis of the profile of construction organisations suggest that the research participants work for viable construction organisations that are representative of the South African construction industry.

Table 5.2: Profile of construction organisations

Answer Choices	Response Percent	Response number
Location of head office		
KwaZulu-Natal	31.6%	176
Gauteng	19.39%	108
Eastern Cape	16.34%	91
Western Cape	13.29%	74
Limpopo	6.46%	36
Free State	5.75%	32
Mpumalanga	5.75%	32
Northern Cape	5.21%	29
North-West	4.67%	26
Number of employees		
Less than 50 employees	87.05%	464
51 - 200 employees	7.13%	28
More than 200 employees	5.82%	31
Company age		
6 - 10 years	34.4%	193
Less than 5 years	24.96%	140
11 - 15 years	19.79%	111
21 years and above	13.01%	73
16 - 20 years	8.02%	45
Region of operation		
Provincial-level	40.97%	229
Local-level	34.88%	195
National level	28.8%	161
Regional level	13.42%	75
International level	8.77%	49

5.3 Characteristics of BBCPs

This section presents the analysis of the characteristics of BBCPs (*category of the project, type of client for the project,* and *modalities for sharing the BIM adoption cost on the project*), extent of use of BIM software technologies (*BIM software technologies used for the project, stages where (a) the BIM software technologies,* and *(b) BIM principles were used for the project*), BIM process – extent of collaboration (*size of the project consulting team, BIM supply chain for the project, the collaborative procurement process for the project*, and *formation of project teams for the project*), BIM processes – extent of integration (*level of development of the information models for the projects, level of objects' clarity, BIM capacity,* and *BIM principles*), project complexity (*political and cultural sensitivity of the* *project, regulatory requirements for the project, duration of the project, project size, project milestones and deadlines, construction technologies,* and *systems used for the project*), and project expectations (*cooperation, coordination, partial integration,* and *full integration*).

Figures 5.1 discussed subsequently provides the analysis of the characteristics of the BBCPs executed by the 872 construction professionals (research participants) towards identifying and validating the pattern of matching the extent of BIM adoption to the level of project complexity and expectations of the BBCPs. These characteristics include the category of the project, type of client for the project, and modalities for sharing the BIM adoption cost. With respect to the category of the projects, the majority of the BBCPs executed by the research participants were *buildings for domestic use* (52.97%), *roads* (45.66%), *commercial buildings* (29.22%), *industrial buildings* (29.22%), and *institutional building* (28.31%). Construction projects, such as *ports and harbours* (3.2%) *fibre optic and water reticulation* (1.5%), *mining facilities* (1.1%), were very few in the category of BBCPs executed by the research participants. A predominant number of the BBCPs executed by the research participants had *private sector* (56.25%) and *provincial department* (47.77%) as clients. Fewer BBCPs executed by the research participants had *public-private partnerships* (18.3%) and *metropolitan department*s (17.41%) as clients.

The ratio, *client (0%): project team (100%),* was the highest (58.33%) in modalities for sharing the cost of software technologies, hardware, technical support, training, and BIM-related services incurred for the BBCPs involved in by the research participants. Clients had shared the cost of BIM adoption on construction projects with the project team on fewer BBCPs.

5.3.1 BIM software platforms adopted for the BBCPs

Figure 5.2 revealed the extent of the use of BIM software platforms for the BBCPs. The extent of the use of BIM software platforms is determined by the type of BIM software tools used, and the phase of BIM application. Pertaining to the type of BIM software technologies used for the BBCPs *ArchiCAD* (16.67%), and *Revit* (16.15%) were the popular BIM software platforms used for the BBCPs

PROFILE OF BIM-BASED CONSTRUCTION PROJECTS

CATEGORY OF THE BBCPs

Ports and Harbour	3.20%
Airports	3.65%
Railways and Tunnels	4.11%
Commercial Buildings	29.68%
Industrial Buildings	29.22%
Institutional Buildings	28.31%
Buildings for Domestic Use	52.97%
Bridge and Culvert	15.98%
Dams	9.59%
Roads	45.66%

CLIENTS FOR THE BBCPs

Private Public Partnership	18.30%
Regional/District Department	23.66%
Metropolitan Department	17.41%
Provincial Department	47.77%
National Department	28.57%
Public Corporation	29.46%
Private Sector	56.25%

MODALITIES FOR SHARING THE COST OF SOFTWARE TECHNOLOGIES HARDWARE, TECHNICAL SUPPORT, TRAINING, AND BIM -RELATED SERVICES INCURRED FOR THE PROJECTS

Client - 40%: Project Team - 60%	5.09%
Client - 30%: Project Team - 70%	9.26%
Client - 10%: Project Team - 90%	10.19%
Client - 20%: Project Team - 80%	12.50%
Client - 50%: Project Team - 50%	16.67%
Client - 0%: Project Team - 100%	58.33%

Figure 5.1: Profile of BIM-based construction projects (BBCPs).

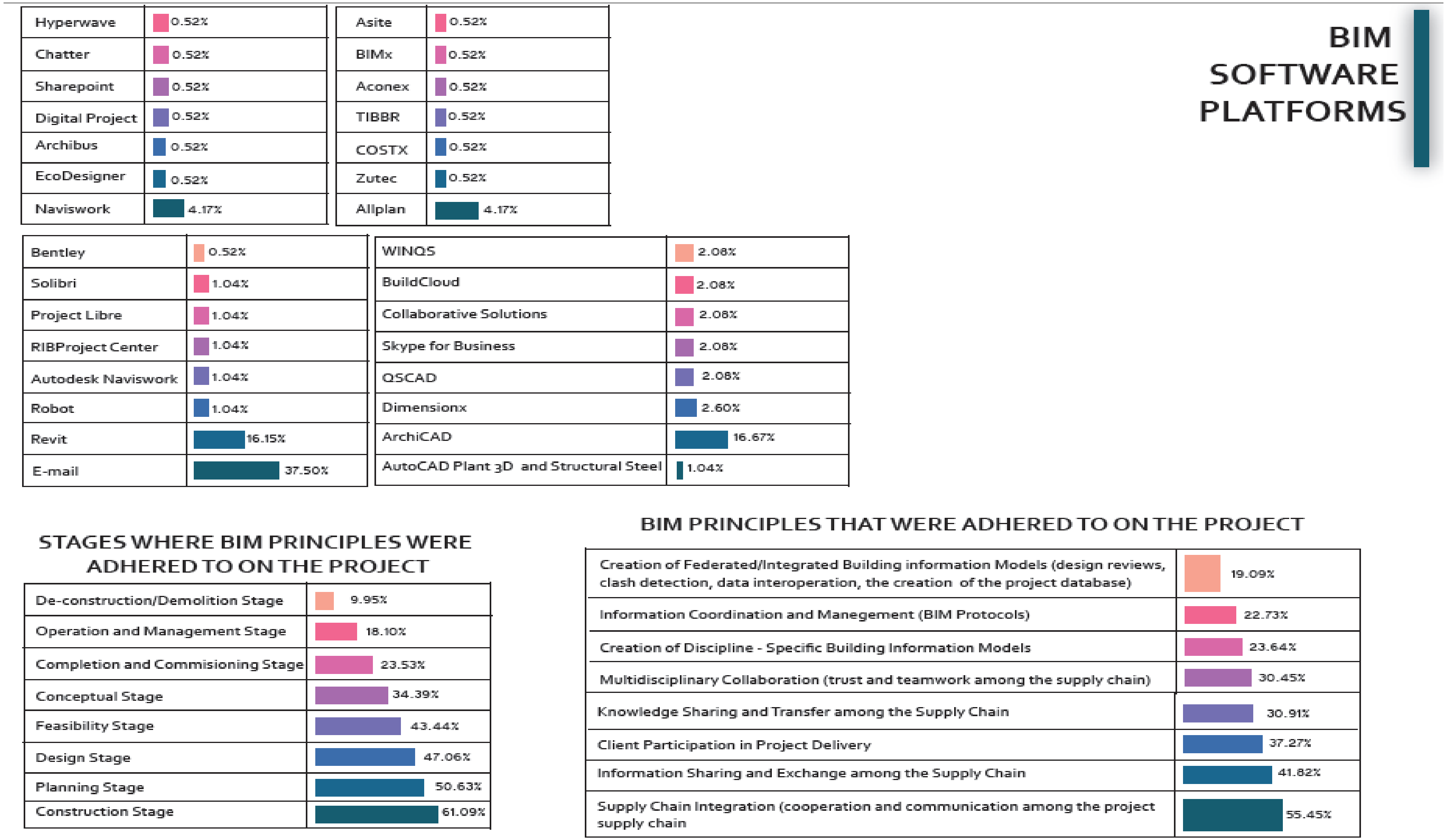

Figure 5.2: Extent of use of BIM software platforms for the BBCPs

by the research participants. The results revealed that BIM software platforms had been used predominantly at stages, such as *construction stage* (54.95%), *planning stage* (52.7%), *design stage* (49.55%), *feasibility stage* (42.79%), and *conceptual stage* (36.04. BIM principles were mostly adhered to on the BBCPs at the construction stage (61.09%), planning stage (50.68%), design stage (47.06%), feasibility stage (43.4%), and conceptual stage (34.39%). It is apparent from this result that the general BIM software platforms are used in the major project stages and in line with the BIM standards and norms. Revit and ArchiCAD were the dominant desktop-based BIM software technologies utilized for the BBCPs. These findings agree with the conclusions by Olatunji (2011) and Zhang et al. (2016).

5.3.2 BIM processes adopted for the BBCPs

The extent of collaboration consists of the size of the BIM supply chain (that is, the core and direct participants in the BIM process and application), the type of collaborative procurement, the size of the project consulting team, and the formation of the project team. As shown in Figure 5.3, the BIM supply chain for the BBCPs were regularly and commonly composed of *main contractor* (67.83%), *structural/civil engineer* (64.78%), *quantity surveyor* (53.91%), *project manager* (53.48%), *architect* (49.57%), *electrical engineer* (37.83%), and *mechanical engineer* (33.91%). Most of the BBCPs executed by the research participants had *2-12 construction professionals and construction subcontractors* as the members of the project team (36.7%); while there were fewer BBCPs with more than *46 construction professionals and construction subcontractors* as the members of the project team (11.4%).

As regards the type of collaborative procurement, the results showed that *integrated project delivery* had been used for 19.28% of the BBCPs executed by the research participants. Only *design-bid-build* (42.15%), *management contract* (34.53%), and *design and build* (25.11%) had been used for more than 20% of the BBCPs. As explained in Figure 5.3, *in-house project team* (48.68%), *the integrated project team* (39.04%), and *collaborative supply team* (28.51%) had been used as the project team formation method for more than 20% of the BBCPs executed by the research participants. From the result, it can be seen that the extent of collaboration did not usually include the suppliers and subcontractors. As expected, BIM-friendly conventional procurement systems were favoured over integrated project delivery. This may be as a result of familiarity with these conventional procurement systems. A surprising finding is the limited use of integrated project delivery as a collaborative procurement system. Integrated project delivery is a procurement system that was developed to integrate BIM processes, systems, platforms, and supply chains towards optimizing a successful BIM adoption and successful BIM-based construction projects. In line with the argument by Alreshidi et al. (2017), the use of integrated project delivery for BBCPs may be limited owing to the new contractual requirements that are needed for its implementation. The extent of integration was conceptualized to consist of the level of development of the building information models for the project, level of objects' clarity, the extent of use of BIM capacity (skills and competencies), and extent of adhering to BIM principles on the BBCPs. Concerning the level of development of the building information models for the project, Figure 5.3 revealed that all the levels of development (LOD) (*LOD 100, 200, 300, 350, 400,* and *500*) had been used for more than 20% of the BBCPs. Only *LOD 300, LOD 100,* and *LOD 200* had been used for more than 30% of the BBCPs (*LOD 300* [47.93%], *LOD 100* [42.86%], and *LOD 200* [32.28%]).

Concerning the levels of objects' clarity, *G3 – Rendered* (18.13%) and *G2 – Defined* (17.47%) had a high level of use. Figure 5.3 revealed *Multidisciplinary collaboration skills* (16.83%) and *Competence in 3D CAD tools* (15.14%) as the dominant BIM capacity. As regards the BIM principles that were adhered to on the BBCPs, more than 20% of the BBCPs were executed in line with principles, such as *supply chain integration* (55.45%), *information sharing and exchange among the supply chain* (41.82%), *client participation in project delivery* (37.27%), *knowledge sharing and transfer among the supply chain* (30.91%), *trust and teamwork* (30.45%), *creation of discipline-specific building information models* (23.64%), and *information coordination and management* (22.73%).

Federated building information models were created for 19.09% of the BBCPs executed by the research participants. From the results, it is apparent that the CAD experience and competence of the BIM supply chain were much pronounced in the BIM capacity that was employed for the BBCPs. This implies that CAD experience and competence are perceived as the basic and integrated part of BIM adoption. In addition, the results showed that the BIM adoption strategy for the BBCPs articulated the service requirements and design details and

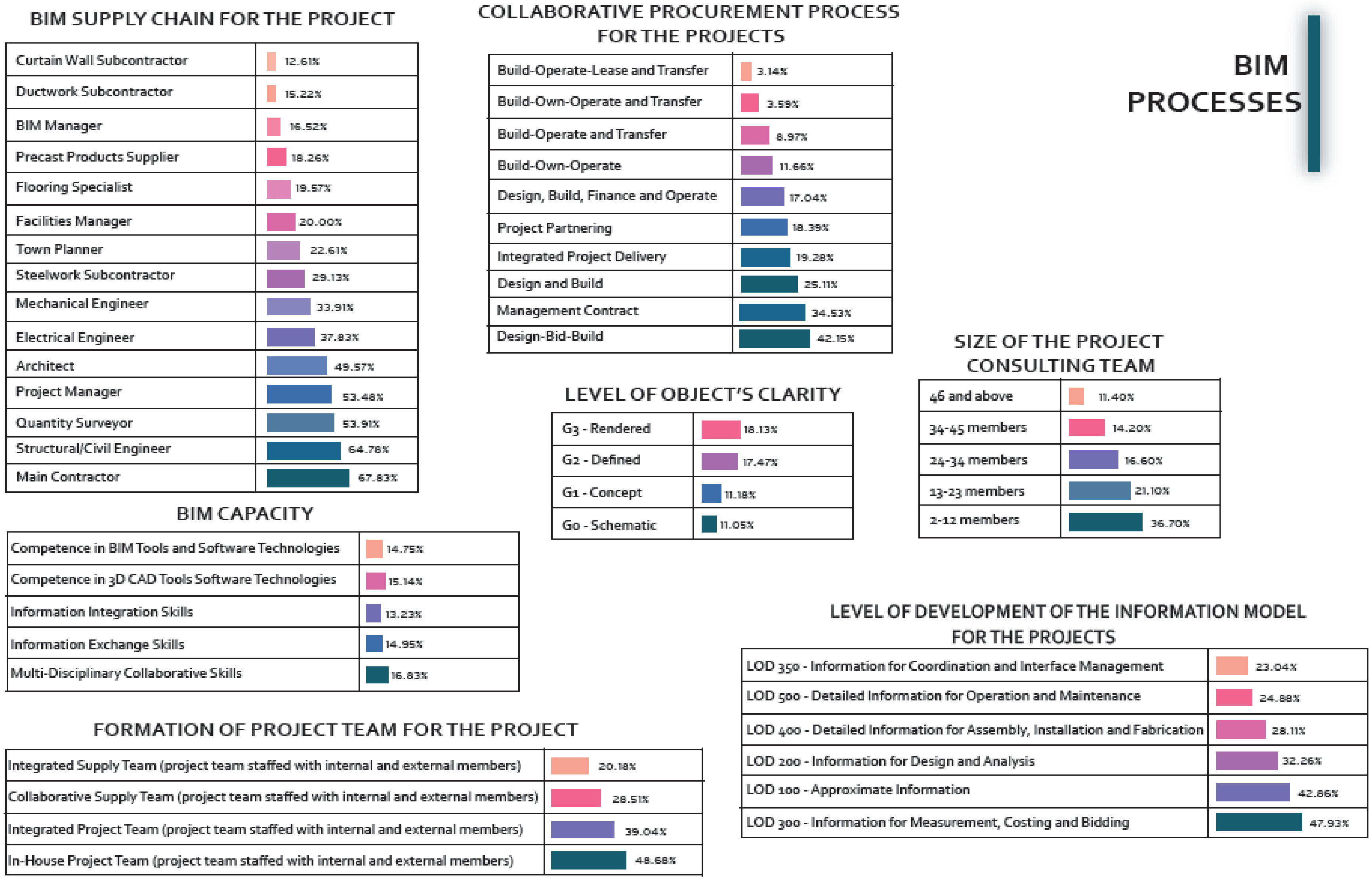

Figure 5.3: BIM processes employed for the BBCPs

PROJECT COMPLEXITY

PROJECT SIZE / TENDER SUM

R6.5Million - R40Million	16.81%
Above R40Million	19.47%
R2Million - R6.5Million	30.97%
Below R2Million	42.92%

THE POLITICAL AND CULTURAL SENSITIVITY OF THE PROJECT

Very High Political and Cultural Implications	11.69%
High Political and Cultural Implications	24.24%
Little High Political and Cultural Implications	35.93%
No High Political and Cultural Implications	36.80%

DURATION OF THE BBCPs

1 year and above	47.79%
6 months - 1 year	31.86%
3 - 6 months	23.45%
Less than 3 months	16.37%

REGULATORY REQUIREMENTS FOR THE PROJECT

Technologies that need new regulatory requirements	11.35%
Standard Regulations	91.70%

PROJECT MILESTONES AND DEADLINES

Over-ambitious Milestones and Deadline (Target dates that are fixed based on very high aspiration and are very difficult to achieve)	7.83%
Ambitious Milestone and Deadline (Target date that are fixed based on high aspirations and are difficult to achieve)	16.52%
Aggressive Milestone and Deadline (Target dates that are fixed and pursued in determined and forceful way)	35.65%
Flexible Milestone and Deadline (Target dates that are not fixed but created as the project proceeds)	50.00%

CONSTRUCTION TECHNOLOGIES AND SYSTEMS USED FOR THE PROJECT

Unproven and New Technologies and Systems	8.04%
Innovative/Ground-Breaking Technologies and Systems	17.41%
Proven but New Technologies and Systems	25.45%
Conventional Technologies and Systems	67.73%

Figure 5.4: Project complexity of the BBCPs

specifications as revealed by the level of development employed for the projects. This indicates a proven strategy for regulating the quality and contents of building information models. This corroborates the conclusions by Boton et al. (2015), Solihin and Eastman (2015), and Leite et al. (2011), which indicated that the level of development employed for BBCPs serves as the framework managing the quality, contents, costs, and benefits of BIM.

5.3.3 Project complexity of the BBCPs

The results, as shown in Figure 5.4, indicate that 42.92% of the projects had a tender sum of less than R2 million, 30.97% had a R2 million - R6.5 million tender sum, 19.47% had a tender sum of more than R40 million, and 16.81% of the projects had a tender sum between R6.5 million - R40 million. The greater number of BBCPs had a duration of 1 year and above (47.79%) and 6 months to 1 year (31.86%). Not many of the BBCPs had less than 3 months (16.37%) as their duration.

The results also show that flexible milestone and deadline (50.0 %) was common to the BBCPs executed by the research participants. The use of conventional technologies and systems (64.73%) was common to the BBCPs, while the greater number of the BBCPs executed by the research participants had no political and cultural implications (36.8%), and few political and cultural implications (35.93%). The predominant requirements for the BBCPs were the standard regulations (91.7%). Based on these results, it can be inferred that the BIM adoption strategies incorporated project milestones and deadline, construction technologies and systems, political and cultural sensitivity of projects, and regulatory requirements for the projects into the evaluation of project complexity for BIM adoption. This corroborates the conclusions of Cao et al. (2015) and Lattifi et al. (2013) on the relationship between the degree of BIM adoption on construction projects and the degree of project complexity.

5.3.4 Project expectations of the BBCPs

The results, as revealed in Figure 5.5, show that the major cooperation benefits that were realized on BBCPs are *improved client participation* (19.21%)

PROJECT EXPECTATIONS

COOPERATION

Improved Client Participation	19.21%
Improved Marketing	16.57%
Reduced Contractual Claims	16.00%
A Valued and Quick Decision Making	18.97%
Improved Client Satisfaction	24.28%
Fewer Change Order	13.61%
Few Requests for Information	13.79%
Broaden the Understanding of Project Needs	18.75%
Increased Labor Productivity	19.32%

PARTIAL INTEGRATION

Performance Simulation	13.56%
Increase Information Exchange	19.66%
Increased Knowledge Transfer	25.00%
Eliminate Waste	15.00%
Improved Safety Management	22.78%
Coordinated Decision Making	17.44%
Enhanced Service Quality	16.18%
Effective Supply Chain Management	13.14%

COORDINATION

Improved Work Quality	26.44%
Allows Clash Detection	15.43%
Allow Design Review	18.02%
Enable e-Procurement of Material and ..	13.89%
Improved Team Culture	16.11%
Competitive Advantage	14.84%
Improved Information Quality	19.23%

FULL INTEGRATION

Improved Prefabrication	9.60%
Easy Retrieval of Data	15.08%
Intelligent Documentation	15.25%
Enhanced Data Interoperability	10.73%
Integrated and Interactive Database	15.64%
Improved Energy Performance	8.94%
Supply Chain Integration	12.36%
Trust and Commitment	21.97%
Improved Operation and Maintenance	13.37%
Improved Deconstruction Management	10.29%

Figure 5.5: Project expectations of the BBCPs

, *improved client satisfaction* (24.28%), *increased labour productivity* (19.32%), *valued and quick decision-making* (18.97%), and *broaden(ing) the understanding of project needs* (18.75%). *Improved information quality* (19.23%), *improved work quality* (26.44%), and *allow(ing) design review* (18.02%) were the foremost coordination benefits that were realized on the BBCPs.

With regard to full integration benefits, Figure 5.5 revealed *trust and commitment* (21.97%), *easy retrieval of data* (15.08%), *intelligent documentation* (15.25%), and *integrated and interactive database* (15.64%) as the leading benefits that were realised on the BBCPs.

The figure showed that increased information exchange (19.66%), increased knowledge transfer (25%), improved safety management (22.78%), and coordinated decision-making (17.44%) were the notable partial integration benefits that were achieved on the BBCPs. It could not be ascertained from this result if these project expectations were the targets of the BIM adoption strategies adopted for the BBCPs. However, it is apparent from the results that the BIM benefits that were realised on the BBCPs relate to the integrated expectations of clients, projects, and participants during BIM adoption planning and execution.

These findings suggest that cooperation took place between the clients for the BBCPs and the BIM-SCM through client participation in the design review. It is likely that the cooperation made it possible for the BIM-SCM to understand the needs of the clients and to make a valued and quick decision. The findings also suggested that the degree of coordination that took place among the BIM-SCM improved the quality of the construction processes and project information. It may also be inferred from the results that the BIM process (integration and collaboration) ensured the occurrence of knowledge transfer, information exchange, trust, and project documentation. These explanations are in line with the benefits of BIM adoption on construction projects as reported by Ghaffarianhoseini et al. (2017) and Liu et al. (2017).

5.4 Mean item score analysis

A mean item score (MIS) analysis was conducted in order to achieve the first four objectives of this research. The following sub-sections present the results of the mean item score of the responses surrounding the strategies for driving BIM adoption on construction projects, the indicators of a reduction in barriers against (preliminary and sustained) BIM adoption on construction projects, the level of BIM adoption on construction projects, and the levels of integration and collaboration among the BIM supply chain members.

5.4.1 MIS of the BIM implementation strategies driving BIM adoption.

The first objective of this research was to identify the BIM implementation strategies that are currently in useto drive BIM adoption on construction projects (that is, BIM implementation strategies that are employed to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects). To achieve this objective, this research conceptualized the BIM implementation strategies to consist of *BIM commitments, BIM motivations, BIM capacity developments,* and *BIM utilisation*. The research participants were asked to rate their level of agreement with the identified BIM implementation strategies on a five-point Likert scale. The five (5) point Likert scale that was adopted for quantitative data collection entails *1= 'highly disagree', 2= 'disagree', 3= 'true to some extent', 4= 'agree', 5= 'highly agree'*.

Mean item score (*MIS*) was used to analyse the responses, and a cut-off value of 3.41 was used to determine the highly significant BIM implementation strategies as indicated by the research participants. As Table 5.3 in **Appendix A** shows, the highly significant BIM motivations are *Need to improve organisational performance and efficiency in the long term* (*MS*=3.82), *Need to improve organisational performance and efficiency in the short term* (*MS*=3.79), *Need to improve competitiveness in project bidding* (*MS*=3.76), *Need to adapt to global trends* (*MS*=3.73), *Need to adapt to global best practices* (*MS*=3.72), *The possibility of getting high-value clients* (*MS*=3.60), *Prevalent BIM adoption among the top and successful firms* (*MS*=3.56), and *BIM adoption as a way of supporting development in the construction industry* (*MS*=3.55).
Other highly significant BIM motivations are *Report of BIM usage on widely acclaimed successful projects* (*MS*=3.55), *Need to be seen as being up-to-date and technologically sophisticated* (*MS*=3.55), *BIM adoption as part of project team requirement* (*MS*=3.54), *BIM adoption among peer firms* (*MS*=3.52), *Availability of information on BIM concepts* (*MS*=3.49), *BIM adoption as conformity to regulations and rules* (*MS*=3.48), *BIM adoption as part of clients' requirement* (*MS*=3.46), *Need to be socially acceptable to the clients* (*MS*=3.45), and *Publication of BIM success stories* (*MS*=3.41).

Table 5.4 in **Appendix A** reveals the following BIM commitments to be significantly employed by the top management of construction organisations: *Coordination of the BIM process in the organisation* (*MS*=3.54), *Educating staff on the potentials of BIM* (*MS*=3.54), *Introduction of collaborative teamwork culture in the organisation* (*MS*=3.53), *Allowing staff* *members to participate in the work process and redesign process* (*MS*=3.53), *Development of new values for staff members* (*MS*=3.49), *Effective communication between stakeholders* (*MS*=3.47), *Incorporation of BIM into the vision of the organisation* (*MS*=3.44), *Development of communication styles* (*MS*=3.42), *Development of new management processes* (*MS*=3.41), and *Ensuring effective use of BIM tools* (*MS*=3.41).

As Table 5.5 in **Appendix A** shows, the significant strategies for BIM capacity development are *Self-initiated BIM training* (*MS*=3.56), *BIM workshops* (*MS*=3.55), *BIM seminars* (*MS*=3.53), *On-the-job BIM training for the employees* (*MS*=3.53), *BIM technology educational program in colleges, technical and vocational institutes* (*MS*=3.50), *BIM application and management programme at post-graduate level in the university* (*MS*=3.49), *BIM education at the undergraduate programme at the university* (*MS*=3.44), and *Corporate BIM training partners* (*MS*=3.42).

As shown in Table 5.6 (see **Appendix A**), the significant strategies for BIM utilisation are *Determining the appropriate form of collaboration required for the project* (*MS*=3.60), *Determining the appropriate import and export file format for the project* (*MS*=3.600, *Determining the appropriate intensity of collaboration required for the project* (*MS*=3.59), *Determining the appropriate BIM maturity levels for the project* (*MS*=3.560, *Determining the appropriate BIM platform for the project* (*MS*=3.56), *Determining the appropriate collaborative procurement system* (*MS*=3.49), *Assessing the performance of BIM adoption on the project* (*MS*=3.47), *Developing digital object identifiers for building materials manufacturers* (*MS*=3.46), and *Determining the appropriate level of development of building information models* (*MS*=3.45).

5.4.2 MIS of the indicators of a reduction in barriers to BIM adoption.

The second objective of this research was to establish the indicators of a reduction in barriers against preliminary and sustained BIM adoption on construction projects. In order to achieve this objective, the research participants were asked to identify the barriers against preliminary and sustained BIM adoption on construction projects. This was done so as to understand the nature of the barriers against BIM adoption. The occurrence of the barriers against BIM adoption was rated by the research participants on a five-point Likert scale. In the Likert scale, *1= 'very low occurrence', 2= 'low occurrence', 3= 'somewhat high occurrence', 4= 'high occurrence', and 5= 'very high occurrence'*.

The mean item score (*MS*) analysis for the barriers against preliminary BIM adoption on construction projects is presented in Table 5.7 (see **Appendix A**). Table 5.7 shows that the following barriers occurred significantly on construction projects: *The absence of in-house BIM competent professionals* (*MS*=3.55)**,** *Lack of resources to train employees* (*MS*=3.53)**,** *Unavailability of BIM competent professionals in the labour market* (*MS*=3.51)**,** *Lack of cooperation among firms in the industry* (*MS*=3.51)**,** *Lack of understanding of BIM* (*MS*=3.50)**,** *Non-communication of BIM concept by relevant industry leadership* (*MS*=3.50)**,** *Lack of cooperation among professionals in the industry* (*MS*=3.50)**,** *Lack of BIM awareness among clients* (*MS*=3.50)**,** *Lack of enforcement from industry leadership* (*MS*=3.48)**,** *Lack of awareness of BIM* (*MS*=3.47)**,** *Lack of business case for BIM adoption* (*MS*=3.47)**,** *Lack of resources to acquire BIM tools and technologies* (*MS*=3.44)**,** and *Lack of enforcement from government agencies* (*MS*=3.41).

Table 5.8 in **Appendix A** shows the mean score of responses about the barriers against sustained BIM adoption on construction projects. It is apparent from Table 5.8 that *Lack of information on BIM tools and technologies* (*MS*=3.47), *Top management not engaging BIM consultants to facilitate BIM usage* (*MS*=3.47), *Lack of understanding and identification of BIM tools and technologies* (*MS*=3.43), *Failure to understand how BIM adoption will change business processes* (*MS*=3.43), and *Lack of coordination across different supply chain members* (*MS*=3.42) are the significant barriers to sustained BIM adoption on construction projects.

Thirty-two indicators of a reduction in barriers against preliminary and sustained BIM adoption were conceptualised and presented to the research participants, requiring them to rate their level of agreement that the proposed indicators would work on a five-point Likert scale. In the scale, *1 represents highly disagree, 2 represents disagree, 3 represents true to some extent, 4 represents agree, and 5 represents highly agree.* The responses were analysed using mean item score at a significance level of 3.41.

Table 5.9 in **Appendix A** presents the mean score of the responses to the indicators of a reduction of barriers against (preliminary and sustained) BIM adoption on construction projects. It is evident from Table 5.9 that *Acquisition of resources for BIM training of employees* (*MS*=3.48), *Acquisition of BIM software technologies* (*MS*=3.47), *BIM-induced changes in construction business process* (*MS*=3.45), *Availability of BIM infrastructures in the organisations* (*MS*=3.42), *Availability of policies and regulations on copyright* *ownership* (*MS*=3.41), and *Employees' readiness to accept changes* (*MS*=3.41) are the indicators of a reduction of barriers against (preliminary and sustained) BIM adoption on construction projects.

5.4.3 MIS of the level of BIM adoption.

The third objective of this research was to establish the level of BIM adoption on construction projects. To achieve this objective, this research conceptualised that the level of BIM adoption on construction projects consists of the *criteria for assessing BIM performance*, *BIM capacity (BIM skills and competence) utilised*, *BIM tools employed*, *types of building information models developed*, and *level of clarity of objects that were used to develop building information models* for the BIM-based construction projects. In the questionnaire, the research participants were asked to rate on a five-point Likert scale the extent to which they employed BIM tools, assessed BIM performance using the identified BIM performance assessment criteria, developed different types of building information models, and employed the identified level of objects' clarity. In the Likert scale, *1 represents 'Not at all', 2 represents 'Rarely', 3 represents 'To Some Extent', 4 represents 'Moderate Extent', and 5 represents 'To a Large Extent'*.

A five-point Likert scale was also used for the question on the BIM capacity utilised for the BIM-based construction projects. However, in this scale *1 stands for 'entry-level', 2 stands for 'functional level', 3 stands for 'expert level', 4 stands for 'specialist level', and 5 stands for 'experience level'*. The mean score analysis was conducted for the responses and fixed at a significant level of 3.41 and above for high significant items and a significant level of 2.61 – 3.40 for low significant items. Table 5.10 in **Appendix A** shows the mean score of responses to criteria for assessing BIM performance on BIM-based construction projects. The results from Table 5.10 (see **Appendix A**) revealed *Improved work quality* (*MS*=3.54), *Improved client satisfaction* (*MS*=3.53), *Fast project delivery* (*MS*=3.49), *Effective communication* (*MS*=3.46), *Broaden the understanding of project needs* (*MS*=3.44), and *Increased knowledge transfer* (*MS*=3.42) as the criteria that are moderately used to assess BIM performance on construction projects.

Table 5.11 in **Appendix A** shows the mean score of responses to BIM capacity (BIM skills and competence) utilised on BIM-based construction projects. As shown in Table 5.11, the

BIM capacity utilised for the BIM-based construction projects was at the expert level and mainly focused on *Competence in 3D CAD tools and software technologies* (*MS*=2.74) and *Information integration skills* (*MS*=2.70). The mean score of responses to BIM tools employed on BIM-based construction projects is presented in Table 5.12 (see **Appendix A**). It is evident in Table 5.12 that *Budget simulation* (*MS*=3.18), *Construction sequencing* (*MS*=3.15), and *Visualization/rendering* (*MS*=3.11) are the BIM tools that are significantly employed on BIM-based construction projects. As Table 5.13 in **Appendix A** shows, the building information models that are highly favoured for BIM-based construction projects are as follows: *Construction plan and schedule* (*MS*=3.55), *Construction health and safety information model* (*MS*=3.41), *Cost and quantities of information model* (*MS*=3.39), *Structural information model* (*MS*=3.38), *Construction system information model* (*MS*=3.36), *Architectural information model* (*MS*=3.33), *Electrical services information model* (*MS*=3.20), *Structural steelwork fabrication information model* (*MS*=3.19), *Mechanical services information model* (*MS*=3.03), and *Lighting analysis information model* (*MS*=3.00).

Table 5.14 in **Appendix A** shows the mean score of responses to the level of clarity of objects that were used to develop building information models for BIM-based construction projects. It is evident from Table 5.14 that the level of objects' clarity was only used to some extent on BIM-based construction projects [*G3 – Rendered* (*MS*=3.00) and *G2 – Defined* (*MS*=2.94)].

5.4.4 MIS of the levels of integration and collaboration.

The fourth objective of this research was to determine the levels of integration and collaboration among the BIM supply chain members. To achieve this objective, this research conceptualised that the levels of integration and collaboration among the BIM supply chain members depend on the level of trust-based relationships, information sharing and exchange, knowledge sharing and transfer, and network communication. The research participants were asked to evaluate how often trust-based relationships, information sharing and exchange, knowledge sharing and transfer, and network communication occurred among the BIM supply chain members. The evaluation was done on a five-point Likert scale where *1= 'Not at all', 2= 'Rarely', 3= 'To some extent', 4= 'To a moderate extent', 5= 'To a large extent'.*
Responses were analysed using mean item score, and 3.41 point was taken as the significant level for the Likert items. Table 5.15 in **Appendix A** shows the mean score of responses

surrounding trust-based relationships among the BIM supply chain members. In the Table, the following items were found to have high significance: *Problem-solving ability* (*MS*=3.85), *Competence of personnel* (*MS*=3.84), *Competence of organisations* (*MS*=3.69), *Consistent integrity* (*MS*=3.660, *Openness in sharing information* (*MS*=3.65), *Mutual exchange of ideas* (*MS*=3.59), *Honesty and mutual commitment* (*MS*=3.55), *Freedom to state opinions and perspectives* (*MS*=3.51), *Cross-functional cooperation* (*MS*=3.500), *Display of confidence for one other by supply chain members* (*MS*=3.50), *Support for innovation and learning* (*MS*=3.48), *Shared interests and project expectations* (*MS*=3.470, *Conflict resolution* (*MS*=3.46), *Inter-personal relationship* (*MS*=3.43), and *Inter-organisational relationship* (*MS*=3.43).

Table 5.16 in **Appendix A** shows the mean score of responses surrounding information sharing and exchange among the BIM supply chain members. According to the table, the elements of information sharing and exchange with a high level of occurrence are *Information shared is credible* (*MS*=3.73), *Clarity of information* (*MS*=3.67), *The high quality of information* (*MS*=3.66), *Information shared is accurate* (*MS*=3.60), *Usage of collaborative electronic media for information sharing* (*MS*=3.53), *Timely sharing of information* (*MS*=3.53), *Adequacy of information* (*MS*=3.47), *Enhanced interpersonal sharing and exchange of information* (*MS*=3.46), and *Selection of information sharing channels* (*MS*=3.42).

Table 5.17 in **Appendix A** shows the mean score of responses about network communication among the BIM supply chain members. The table reveals the following elements of network communication as having a high level of occurrence: *Documentation of communication* (*MS*=3.78), *Formation of open and formal communication channels* (*MS*=3.76), *Communication across the stages in the project life-cycle* (*MS*=3.70), *Regular interpersonal communication* (*MS*=3.66*), Adoption of common electronic communication platforms* (*MS*=3.64), *Establishment of a secured line of communication* (*MS*=3.61), *Usage of communication protocols* (*MS*=3.61), *Regular team communication* (*MS*=3.58), and *Real-time communication* (*MS*=3.55). According to Table 5.17 in **Appendix A**, the following elements of network communication also have a high level of occurrence: *Feedback communication* (*MS*=3.55), *Regular inter-group communication* (*MS*=3.53), *Timely communication* (*MS*=3.51), *Flexibility of formalities* (*MS*=3.50), *Regular inter-organisational communication* (*MS*=3.50), *Positive corporate communication* (*MS*=3.49), *the multi-*

directional flow of information (*MS*=3.48), and *Adoption of joint problem-solving techniques* (*MS*=3.46).

Table 5.18 in **Appendix A** presents the mean score of responses surrounding knowledge sharing and transfer among the BIM supply chain members. As shown in the table, the elements of knowledge sharing and transfer with a high level of occurrence are *Valued decision-making* (*MS*=3.75), *Understanding of information* (*MS*=3.72), *Quick decision-making* (*MS*=3.70), *the high quality of information* (*MS*=3.65), *Collective decision-making* (*MS*=3.63), *Willingness to share resources* (*MS*=3.60), *Inter-personal knowledge sharing* (*MS*=3.60), *Inter-team knowledge sharing* (*MS*=3.57), *Usage of collaborative electronic media for knowledge sharing* (*MS*=3.52), and *Identification of clashes and omission in information models* (*MS*=3.49). Also, the following elements of knowledge sharing and exchange were revealed to have a high level of occurrence: *Review of projects after completion* (*MS*=3.48), *Sharing of knowledge on best practices among the supply chain members* (*MS*=3.48), *Inter-professional knowledge sharing* (*MS*=3.46), *Database creation and management* (*MS*=3.45), *Inter-group knowledge sharing* (*MS*=3.45), *Knowledge documentation in the form of the project proceeding* (*MS*=3.45), *Sharing of collaborative experiences among the supply chain members* (*MS*=3.42), and *Extraction of measurement information from the information models* (*MS*=3.41).

5.4.5 MIS of the BIM implementation strategies that are required to trigger a reduction in the barriers to BIM adoption.

The BIM implementation strategies that are required in order to drive BIM adoption on construction projects (that is, required to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects) were investigated. This was done to extend the first objective of this research. Understanding which BIM implementation strategies are required will enable the understanding of the differences between them and the BIM implementation strategies that are already employed.

Using the same concepts of *BIM commitments, BIM motivations, BIM capacity developments,* and *BIM utilization*, the research participants were asked to rate on a five-point Likert scale their level of agreement that the BIM implementation strategies mentioned are ones that are required to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects. The five (5) point Likert scale that was adopted for data collection entails *1= 'highly disagree', 2= 'disagree', 3= 'true to some extent', 4= 'agree', 5= 'highly* *agree'*. Mean item score (*MS*) was used to analyse the responses, and a cut-off value of 3.41 was used to determine which required BIM implementation strategies the participants indicated are highly significant.

As Table 5.19 in **Appendix A** shows, the highly required BIM commitments are *Educating staff on the potentials of BIM* (*MS*=3.77), *Provision of in-house BIM training* (*MS*=3.74), *Adherence to BIM protocols* (*MS*=3.72), *Exploration of the usage of BIM on pilot projects* (*MS*=3.71), *Provision of technical support services in the organisation* (*MS*=3.71), *Development of management processes* (*MS*=3.69), *Provision of infrastructures (BIM environment) for BIM* (*MS*=3.67), *Effective communication between stakeholders* (*MS*=3.67), *Allowing staff members to participate in the work process redesign process* (*MS*=3.67), *Development of communication styles* (*MS*=3.67), *Introduction of collaborative teamwork culture in the organisation* (*MS*=3.66), *Adherence to the BIM process* (*MS*=3.66), *Documentation of the proceedings of BIM-based projects* (*MS*=3.63), *Creation of a new organisational structure* (*MS*=3.63), *Adaptation of BIM concepts to the organisational culture* (*MS*=3.61), and *Ensuring effective use of BIM tools* (*MS*=3.61).

Other highly required BIM commitments are *Development of new values* (*MS*=3.60), *Incorporation of BIM into the vision of the organisation* (*MS*=3.59), *Anticipating and planning for BIM adoption risk management* (*MS*=3.59), *Coordination of the BIM process in the organisation* (*MS*=3.57), *An increment in the staff development budget* (*MS*=3.57), *Identification of business opportunities in BIM adoption* (*MS*=3.57), *Facilitating solutions to organisations' contingencies of BIM adoption* (*MS*=3.56), *Introduction of new roles and job titles* (*MS*=3.55), *Appointing BIM champions* (*MS*=3.55), *Appointing BIM managers* (*MS*=3.54), *Development of performance measures for BIM adoption* (*MS*=3.52), *Facilitating solutions to projects' contingencies of BIM adoption* (*MS*=3.49), *Stimulating BIM adoption with investments* (*MS*=3.49), *Facilitating solutions to clients' contingencies of BIM adoption* (*MS*=3.48), and *BIM consultants' engagement* (*MS*=3.42).

Table 5.20 in **Appendix A** reveals the following BIM motivations to be significantly required by the top management of construction organisations: *Publication of BIM success stories* (*MS*=3.77), *Need to improve organisational performance and efficiency in the long term* (*MS*=3.74), *Availability of information on BIM concepts* (*MS*=3.73), *Need to improve competitiveness in project bidding* (*MS*=3.71), *BIM adoption among peer firms* (*MS*=3.70), *Need to improve organisational performance and efficiency in the short term* (*MS*=3.70), *BIM adoption as a way of encouraging development in the construction industry* (*MS*=3.68), *Availability of BIM proficient graduates* (*MS*=3.67), *Availability of national BIM standards*

(*MS*=3.67), *Advertisement and programmes for BIM awareness* (*MS*=3.66), *Need to be seen as being up-to-date and technologically sophisticated* (*MS*=3.66), *Need to adapt to global best practices and trends* (*MS*=3.66).

Other highly required BIM motivations are *The possibility of getting high-value clients* (*MS*=3.65), *Government-sponsored BIM-based pilot projects* (*MS*=3.64), *Availability of guidelines on BIM protocols* (*MS*=3.64), *Prevalent BIM adoption among the top and successful firms* (*MS*=3.63), *Report of BIM usage on widely acclaimed successful projects* (*MS*=3.63), *BIM adoption by rival firms* (*MS*=3.61), *Availability of legalities and copyright ownership of BIM* (*MS*=3.60), *Marketing of BIM as professional services* (*MS*=3.60), *Advocacy and campaign for BIM* (*MS*=3.57), *Availability of funds to assist small and medium firms to adopt BIM* (*MS*=3.56), *Availability of guidelines on BIM roles and responsibilities* (*MS*=3.56), *BIM adoption as part of project team requirement* (*MS*=3.55), *Need to be socially acceptable to the clients* (*MS*=3.55), *BIM adoption as part of clients' requirement* (*MS*=3.51), *BIM adoption as conformity to regulations and rules* (*MS*=3.47), *BIM adoption as a marketing strategy* (*MS*=3.47), *BIM adoption as a requirement in the company's supply chain network* (*MS*=3.47), and *Mandatory requirement of BIM for building permit application* (*MS*=3.46).

As Table 5.21 in **Appendix A** shows, the significant strategies that are required for BIM capacity development are *BIM technology educational programme in colleges, technical and vocational institutes* (*MS*=3.79), *On-the-job BIM training for the employees* (*MS*=3.78), *BIM education at the undergraduate programme at the university* (*MS*=3.78), *BIM application and management programme at post-graduate level in the university* (*MS*=3.78), *BIM workshops* (*MS*=3.77), *BIM seminars* (*MS*=3.74), *Self-initiated BIM training* (*MS*=3.69), *Corporate BIM training partners* (*MS*=3.65), *BIM research and development* (*MS*=3.64), *Peer-group-influenced BIM training* (*MS*=3.62), *Pre-labour market-influenced BIM training* (*MS*=3.61), *BIM training during Industrial Training/Internship* (*MS*=3.61), and *2D and 3D CAD education in the secondary school* (*MS*=3.60).

As shown in Table 5.22 (see **Appendix A**), the significant strategies that are required for BIM utilisation are *Assessing the performance of BIM adoption on construction projects* (*MS*=3.85), *Determining the appropriate import and export file format for different types of project complexities* (*MS*=3.76), *Developing digital object identifiers for building materials manufacturers* (*MS*=3.75), *Determining the required BIM capacity of the construction project supply chain members based on the types of project* (*MS*=3.74), *Sharing BIM cost* *and benefits between the client and the supply chain members* (*MS*=3.72), *Determining the appropriate number of professionals to form the construction project supply chain network* (*MS*=3.72), *Developing digital object identifiers for supply chain* (*MS*=3.71), *Determining the appropriate BIM maturity levels for different types of project complexities* (*MS*=3.7), *Determining the appropriate collaborative procurement system for different types of project complexities* (*MS*=3.7), *Determining the appropriate level of development of building information models for different types of project complexities* (*MS*=3.67), *Determining the appropriate form of collaboration required for different types of project complexities* (*MS*=3.67), *Determining the appropriate types of professionals to form the construction project supply chain network* (*MS*=3.64), and *Determining the appropriate intensity of collaboration required for different types of project complexities* (*MS*=3.61).

5.5 Thematic analysis of the qualitative data

Research participants that identified their roles in BBCPs as BIM managers were contacted for interviews. The analysis of these managers' profiles and responses about barriers against sustained BIM adoption on construction projects and BIM implementation strategies employed are discussed in the following sub-sections.

5.5.1 Profile of the interviewees

Table 5.23 presents the distribution of interviewees for the qualitative part of the research, and includes work experience and work responsibilities. All three interviewees were responsible for the management of BIM processes in their respective organisations. One of the interviewees (*interviewer B*) had gathered 20 years of experience in the construction industry, while the other interviewees have less than seven years of work experience in the construction industry.

Table 5.23: Profile of the interviewees

s/n	Interviewee	Work responsibilities	Work experience
1	Interviewee A	Structural engineer/BIM manager	6 years
2	Interviewee B	BIM manager	20 years
3	Interviewee C	BIM manager	5 years

5.5.2 Thematic analysis of the responses to barriers to sustained BIM adoption on construction projects

Structured interviews were carried out on three BIM managers. The interviewees were asked their opinions regarding the barriers preventing the project organisations from adopting BIM on construction projects in response to the results of the survey. Table 5.24 presents the Thematic Analysis of the responses of the interviewees. Two of the interviewees (*interviewee B* and *interviewee A*) indicated that the high cost of BIM adoption and the lack of BIM skills and training are the major barriers preventing the project organisation from experimenting with BIM on construction projects. The result suggests that BIM knowledge, BIM skills, BIM competence, and money for BIM software and hardware are required for preliminary adoption BIM on construction projects.

As for the barriers preventing the continuous usage of BIM at various stages of a project and on subsequent construction projects, two of the interviewees (*interviewee B* and *interviewee A*) indicated that the lack of unified and standardised approach to BIM usage, as well as the lack of processes that support the on-going development of the building information models, are the major barriers to be considered. All three of the interviewees (*interviewee A, B,* and *C*) agreed that the lack of BIM skills and training will prevent the continuous usage of BIM at various stages of a project and on subsequent construction projects. This result implies that the adoption of BIM on a project at any project stage, and different types of the project, depends on the level of BIM skills, BIM knowledge, and BIM competence of the construction professionals and construction subcontractors that are required to participate in the construction projects.

Table 5.24: Thematic analysis of the responses of the interviewees to the barriers preventing the project organisations from adopting BIM on construction projects.

Major theme	Sub-theme	Interviewee
Barriers preventing the project organisations from experimenting with BIM on construction projects.	• The high cost of BIM adoption. • Lack of BIM skills and training.	*Interviewee B and Interviewee A.* *Interviewee B and Interviewee A.*
Barriers preventing the continuous usage of BIM at various stages of a project and on subsequent construction projects.	• Lack of BIM skills and training. • Lack of unified and standardised approach to BIM usage. • Lack of processes that support the on-going development of the building information models.	*Interviewee A, Interviewee B, and Interviewee C.* *Interviewee B and Interviewee A.* *Interviewee B and Interviewee A.*

5.5.3 Thematic analysis of the responses to BIM implementation strategies that are employed to trigger a reduction in the barriers to BIM adoption.

Interviews were conducted that focused on the strategies for driving BIM adoption. The results of the Thematic Analysis of the interviews' responses are presented in Table 5.25. There is a consensus among the interviewees (*interviewees A*, *B*, and *C*) that BIM training and education, change of work processes, creation of new team roles, and subsidy of BIM cost by the client are the appropriate strategies for driving BIM adoption. Two of the interviewees (*interviewee A and B*) agreed that BIM execution plan, strategic use of BIM, and commitment from the stakeholders will help drive BIM adoption on construction projects. This means that the availability of BIM competent professionals, adequate support from the clients, and planning for long-term or overall benefit in BIM adoption are means of achieving a widespread BIM adoption.

Specifically, the interviewees were asked to explain more about the strategic use of BIM on construction projects. All the interviewees (*interviewee A, B,* and *C*) held the same view that finding the balance between BIM adoption and BIM benefits is the only way to achieve a long-term or overall benefit from BIM adoption. This suggests that the benefits of BIM adoption must exceed the cost of BIM adoption, or else BIM adoption on construction projects will not be meaningful.

Table 5.25: Thematic analysis of the responses of the interviewees to the strategies for driving BIM adoption.

Major theme	Sub-theme	interviewee
BIM implementation strategies.	• BIM training and education.	*Interviewee A, B, and C.*
	• Change of work processes.	*Interviewee A, B, and C.*
	• Creation of new team roles.	*Interviewee A, B, and C.*
	• Subsidy of BIM cost by the client.	*Interviewee A, B, and C.*
	• BIM execution plan.	*Interviewee A and B.*
	• Strategic use of BIM.	*Interviewee A and B.*
	• Commitment from the stakeholders.	*Interviewee A and B.*
Strategic use of BIM on construction projects.	• Finding the balance between BIM adoption and BIM benefits.	*Interviewee A, B, and C.*

5.5.4 Thematic analysis of the responses to the use of BIM adoption on construction projects to achieve integration and collaboration among the BIM supply chain.

Table 5.26 shows the thematic analysis of the responses of the interviewees on the use of BIM adoption on construction projects to achieve integration and collaboration among the BIM supply chain. The major benefit of BIM adoption on construction projects is the occurrence of teamwork, trust, cooperation, and shared interests among the project participants. As presented in Table 5.26, all the interviewees (*interviewee A, B,* and *C*) agreed that BIM adoption enables information sharing and extraction, brings greater convergence, and improves relationships among the project participants. This suggests that BIM adoption on construction projects will address the challenges of professional stereotypes and fragmentation among construction professionals.

Table 5.26: Thematic analysis of the responses of the interviewees to the use of BIM adoption on construction projects to achieve integration and collaboration among the BIM supply chain.

Major theme	Sub-theme	Interviewee
Integration and collaboration among the BIM supply chain as a result of BIM adoption on construction projects.	• Enables information sharing and extraction. • Brings greater convergence. • Improves relationship.	Interviewee A, Interviewee B, and Interviewee C. Interviewee A and Interviewee B. Interviewee A and Interviewee B.

5.6 Analysis of the measurement models

This section describes the path analysis (reliability, validity, and consistency analysis) of the measured variables, or measurement models, for the barriers against preliminary BIM adoption on construction projects, barriers against sustained BIM adoption on construction projects, and BIM implementation strategies that are employed to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects. The chapter also presents the path analysis of the measured variables for the indicators of a reduction in barriers against preliminary and sustained BIM adoption on construction projects, level of BIM adoption on construction projects, levels of integration and collaboration among the BIM supply chain members, and BIM implementation strategies that are required to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects.

The path analysis (reliability, validity, and consistency analysis) was done using Confirmatory Factor Analysis, factor loading, correlation coefficient, Eigenvalue, percentage of variance explained, the Kaiser–Mayer-Olkin test, Bartlett's test, mean item score, and Cronbach's alpha test. Confirmatory factor analysis was employed to validate the dimensionality of the measured variables. The homogeneity and convergent validity of the measured variables were tested using factor loading, correlation coefficient, Eigenvalue, Average Variance Explained, the Kaiser–Mayer-Olkin test, and Bartlett's test. Mean item score was used to tests the significance of the measured variables, while Cronbach's alpha was used to test the reliability of the measured variables.

5.6.1 Path analysis of the measured variables for the barriers to preliminary BIM adoption on construction projects.

The barriers to preliminary BIM adoption on construction projects were measured by 22-variables as shown in Table 5.27 (see **Appendix B**). These measured variables are statements describing the barriers against preliminary BIM adoption on construction projects. The research participants were asked to agree or disagree on a Likert scale (see Chapter Four, section 4.5.1, Table 4.1) with those statements that best describe the barriers against preliminary BIM adoption on the BBCPs they had participated in. Analysis such as confirmatory factor analysis, mean item score, and Cronbach's alpha test was conducted to determine the reliability and validity of the measured variables. Confirmatory factor analysis was performed to validate the dimensionality of the measured variables. The homogeneity and convergent validity of the measured variables were tested using factor loading, correlation coefficient, Eigenvalue, percentage of variance explained, the Kaiser–Mayer-Olkin test, and Bartlett's test. Mean item score tested the significance of the measured variables, while Cronbach's alpha tested the reliability of the measured variables.

As explained in Chapter Four, section 4.6.1.2, and Table 4.4, 0.90 is the recommended cut-off value for Cronbach`s alpha, 1.00 for Eigenvalue, 0.60 for the correlation coefficient, 0.6 for the Kaiser–Mayer–Olkin value, 0.5 for the Average Variance Explained, 2.61 for mean item score, and 0.70 for factor loading. The cut-off value for Bartlett's test is based on the significant value of the measured variables, which must be less than 0.05. The results in

Table 5.27 (see **Appendix B**) show that all the measured variables have a Mean item score that is above the cut-off value of 2.61, have a factor loading that is above the cut-off value of 0.70, have a Cronbach's alpha coefficient that is above the 0.90 cut-off value, and have a correlation coefficient that is above the 0.60 cut-off value. The Eigenvalue for the measured variables is 20.59, which is far above the cut-off value of 1.00. The measured variables explained 93.57% of the variance of the barriers against preliminary BIM adoption on construction projects, while the Kaiser-Mayer-Olkin value for the measured variables is 0.97, which exceeds the 0.6 cut-off value. The Bartlett's test of sphericity for the measured variables was significant (x^2 = 52945.60; $p < 0.05$). Based on the tests' results, all the measured variables for the barriers to preliminary BIM adoption on construction projects were found reliable and valid for structural equation modelling.

5.6.2 The barriers against sustained BIM adoption on construction projects.

Twenty-eight (28) variables were measured for the barriers against sustained BIM adoption on construction projects (see Table 5.28 in **Appendix B**). Using a Likert scale, research participants were asked to indicate their level of agreement with a number of statements describing the measured variables for the barriers against sustained BIM adoption on a construction project. The results of the analysis of the measured variables for reliability, consistency, and validity are presented in Table 5.28 (see **Appendix B**). The results show that the measured variables explained 93.79% of the variance of the barriers against sustained BIM adoption on construction projects. The Eigenvalue for the measured variables is 26.26, which is greater than the recommended value of 1.00. This suggests that each of the measured variables contributes to the variance explained by the measured variables. The results show that all the measured variables are significant at a cut-off value of 2.61, while Bartlett's test for the measured variables shows a significant result (x^2 = 70562.95; $p< 0.05$).

Variables *S4* (failure to understand how BIM adoption will change business processes), *S15* (scepticism about the benefits of BIM adoption), and *S23* (conflict of interests between BIM adoption and organisational vision and objectives) have the lowest factor loading of 0.91, while variables *S1* (lack of information on BIM tools and technologies) and *S2* (top management not engaging BIM consultants to facilitate BIM usage) have the highest factor loading of 0.96. These results suggest that the measured variables have a high level of internal consistency based on a cut-off value of 0.70. At a cut-off value of 0.90, the Cronbach's alpha coefficient for the measured variables is 0.99, while the correlation coefficients for the measured variables were far above the cut-off value of 0.60. The KMO value for the measured variable is 0.97, which far exceeds the recommended value of 0.60. These results suggest that the measured variables possess sufficient reliability and validity that are required for structural equation modelling.

5.6.3 The BIM implementation strategies that are employed to trigger a reduction in the barriers to BIM adoption.

Ninety-seven (97) variables and four sub-constructs were used in the questionnaire for measuring the BIM implementation strategies that are employed to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects. Thirty-three (33) measured variables were used for sub-constructs *Y1* (*BIM motivations*), 36 measured variables for sub-constructs *Y2* (*BIM commitments*), 14 measured variables for sub-constructs *Y3* (*BIM capacity development*), and 14 measured variables for sub-constructs *Y4* (*BIM utilization*). The research participants were asked to indicate and rate on a Likert scale the statement that describes the BIM implementation strategies that they had adopted to ensure the application of BIM process and tools on construction projects.

Table 5.29a – Table 5.29d in **Appendix B** present the results of the analysis of the consistency, reliability, and validity of the measured variables. As presented in Table 5.29a (see **Appendix B**), the measured variables for sub-construct Y1 are highly consistent, reliable, and valid. None of the measured variables score below 2.61 cut-off value for the mean item score. This indicates significance. Their variables ($Y1_{12}$, $Y1_{14}$, and $Y1_{18}$) have 0.89-factor loading. This factor loading is the lowest among the measured variables, while 0.95-factor loading is the highest among the measured variables. As the lowest factor loading is 0.89, and 0.70-factor loading is the cut-off value, it shows that there is internal consistency among the measured variables. Cronbach's alpha coefficient for the measured variable is higher than the 0.90 cut-off value. The correlation coefficient, Eigenvalue, percentage of variance explained, and KMO value for the measured variables for sub-constructs *Y1* are all above the cut-off values. At x^2 of 74840.78 and p-value of 0.000, Bartlett's test of sphericity shows significant results.

Consistency, reliability, and validity tests for measured variables for sub-construct *Y2* are presented in Table 5.29b (see **Appendix B**). All the 36 measured variables are consistent, reliable, and valid based on their mean item scores, factor loadings, Cronbach's alpha coefficients, correlation coefficients, Eigenvalue, percentage of variance explained, KMO value, and Bartlett's test results. Table 5.29c (see **Appendix B**) shows the results of the reliability and validity tests conducted for the measured variable of sub-construct *Y3*. At a cut-off value of 2.61, 0.70, 0.90, 0.70, 1.00, and 0.60, all the 14 measured variable are within the recommended values. The measured variables explained 94.90% of the variance of sub-constructs *Y3,* while Bartlett's test of sphericity is significant (x^2 =33678.52, $p< 0.05$). With a least mean item score of 3.26, least factor loading of 0.90, Cronbach's alpha coefficient of 0.99, a correlation coefficient of 0.95, Eigenvalue of 13.30, and KMO value of 0.96, all the 14 measured variables for sub-construct *Y4* are consistent, valid, and reliable (see Table 5.29d in **Appendix B**). The variables explained 95.05% of the variance of sub-constructs *Y4*. The results of the Bartlett's test show a significant result (x^2 = 35040.29, $p < 0.05$). The results that are shown in Table 5.29a – 5.29b (see **Appendix B**) suggest that sub- construct *Y1, Y2, Y3*, and *Y4* have sufficient reliability and validity for structural equation modelling.

5.6.4 The indicators of a reduction in barriers to preliminary and sustained BIM adoption on construction projects.

BIM implementation strategies are meant to drive BIM adoption on construction projects. The use of these strategies by the research participants means that the barriers against preliminary and sustained BIM adoption on construction projects would have been reduced. Hence, the indicators of a reduction in barriers against preliminary and sustained BIM adoption on construction projects were conceptualised and investigated as a construct using 32 measured variables. The research participants were requested to indicate their level of agreement with these 32 measured variables on a five-point Likert scale. Table 5.30 in **Appendix B** presents the results of the validity, reliability, and consistency tests that were conducted for the measured variables to examine whether they achieve an acceptable fit to the data. As shown in Table 5.30 in **Appendix B**, all the mean item scores were above the cut-off value of 2.61, indicating significance.

The results of the factor loading indicate a high correlation among the measured variables, as the factor loadings were above the cut-off of 0.70. Similarly, all the Cronbach's alpha coefficients, correlation coefficient, Eigenvalue, and KMO values were adequate based on the recommended cut-off values. The results of Bartlett's test show that the measured variables have a significant internal consistency (x^2 = 92346.89; $p< 0.05$), while the results of the Average Variance Explained show that the measured variables correspond to the construct that was investigated up to 94.79%. These results show that the measured variables are associated with the indicators of a reduction in barriers against preliminary and sustained BIM adoption on construction projects. The results also suggest that the construct is sufficiently valid and reliable for structural equation modelling.

5.6.5 The level of BIM adoption on construction projects.

BIM-based construction projects were investigated in this research. The characteristics of BIM-based construction projects (BBCPs) were investigated to ascertain the application of BIM tools and principles on those projects. However, to ascertain the understanding of BIM (BIM knowledge) by the research participants and the impacts of BIM adoption on construction projects and project participants, this research conceptualised and investigated the level of BIM adoption on construction projects (that is, the extent of BIM application on the BBCPs). Five sub-constructs, namely critical for assessing BIM performance (*K1*), BIM-capacity of the project participants (*K2*), BIM tools employed on the BBCPs (*K3*), types of building information models developed for the BBCPs (*K4*), and the level of clarity of the parametric objects that were used to develop building information model for the BBCPs (*K5*), were used to explain the level of BIM adoption on the BBCPs that were investigated in this research. These five sub-constructs shared 99 variables, where *K1* has 42 variables, *K2* has five variables, *K3* has 29 variables, *K4* has 19 variables, and *K5* has four variables.

Responses pertaining to the level of BIM adoption on the BBCPs were supplied by the research participants on the questionnaire. The reliability, validity, and consistency tests for the 99 measured variables are presented in Table 5.31a – Table 5.31e (see **Appendix B**). For sub-construct *K1* and *K5*, all the measured variables are significant (that is, mean item scores are above the cut-off value of 2.61), highly correlated (that is, factor loadings are above the cut-off value of 0.70), reliable and have internal consistency (that is, the Cronbach's alpha coefficients are above the cut-off value of 0.90), have discriminant validity (that is, the correlation coefficients are above the cut-off value of 0.70), contributed to the constructs (that is, the Eigenvalues are above the cut-off value of 1.00), have convergent validity (that is, the average variances explained are above 0.50 (50%)), and are true proportions of the constructs (that is, the KMO values are above the cut-off value of 0.6) (see Table 5.31a and 5.31e in **Appendix B**).

Tables 5.31a and 5.31e in **Appendix B** also revealed that the Bartlett's test of sphericity was significant for sub-construct *K1* (x^2 = 7164.36, p<0.05) and *K5* (x^2 = 468.59, p< 00.5). This suggests that variances are equal for all the measured variables. For sub-constructs *K2, K3*, and *K4*, not all the measured variables are consistent, reliable, and valid. Due to their inadequacies (that is, mean item scores not within or above the cut-off value of 2.61, factor loadings not within or above the cut-off value of 0.70, and correlation coefficient not within or above the cut-off value of .70), one variable ($K2_5$) was eliminated for sub-construct *K2*, thirteen variables ($K3_{17}$, $K3_{18}$, $K3_{19}$, $K3_{20}$, $K3_{21}$, $K3_{22}$, $K3_{23}$, $K3_{24}$, $K3_{25}$, $K3_{26}$, $K3_{27}$, $K3_{28}$, and $K3_{29}$) were eliminated for sub-construct *K3*, while two variables ($K4_{18}$ and $K4_{19}$) were eliminated for sub-construct *K4*. All the other measured variables are significant, highly correlated, and reliable, and have internal consistency, have discriminant and convergent validity, contributed to the constructs, are true proportions of the constructs, and have homogeneity of variances. These results suggest that the construct (the level of BIM adoption on construct projects) only has 83 valid and reliable measured variables. This means that structural equation modelling that includes this construct must be coordinated using the valid 83 measured variables.

5.6.6 The levels of integration and collaboration among the BIM supply chain members.

The major positive impact of BIM adoption on construction projects is the occurrence of integration and collaboration among the BIM-based construction projects' participants (BIM supply chain). Following the investigation of the level of BIM adoption on the BBCPs executed by the research participants, this research further investigated the levels of integration and collaboration among the BIM supply chain members. Trust-based relationship (*Z1*), information sharing and exchange (*Z2*), network communication (*Z3*), and knowledge sharing and transfer (*Z4)* were the four sub-constructs that were conceptualised and employed to represent the levels of integration and collaboration among the BIM supply chain members.

These four sub-constructs were measured using 101 variables; where sub-construct *Z1* accounts 30 variables, sub-construct *Z2* account for 21 variables, sub-construct *Z3* accounts for 21 variables, and sub-construct *Z4* accounts for 29 variables. Based on the responses of the research participants, appropriate reliability and validity tests were conducted on the measured variables (see Table 5.32a – Table 5.32d in **Appendix B**). The results in Table

5.32a – 5.32d show that all the measured variables possess sufficient reliability and validity, as all of them are significant, highly correlated, reliable and have internal consistency, have convergent and discriminant validity contributed to the constructs, and are true proportions to the constructs. The Bartlett's test results show that all the measured variables have homogeneity of variance [for *Z1* (x^2 =3116.15, p<0.05), for *Z2* (x^2=48837.07, p<0.05), for *Z3* (x^2=53299.77, p<0.05), and for *Z4* (x^2 =3141.184, p<0.05)].

5.6.7 The BIM implementation strategies that are required to trigger a reduction in the barriers to BIM adoption.

This research investigated the BIM implementation strategies that are required to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects. This was done so as to understand the differences between the BIM implementation strategies in use and the BIM implementation strategies that are required. As a construct, the BIM implementation strategies that are required were measured by 95 variables shared among four sub-constructs. The first sub-contract (*X1*) has 36 variables, *X2* has 32 variables, *X3* has 14 variables, and *X4* has 13 variables (see Table 5.33a – 5.33d in **Appendix B**). The results of the mean item score, factor loading, Cronbach's alpha coefficient, correlation coefficient, Eigenvalue, Average Variance Explained, KMO, and Bartlett's test, as documented in Table 5.33a – 5.33b, show that all the 95 variables have sufficient reliability and validity for structural equation modelling.

5.7 Analysis of the structural models

This section describes the parameter estimates and fit indices for the structural equation models of the hypothesised relationships in objective 5. All the five hypothesised relationships were analysed, discussed, and reported in this section.

5.7.1 Modelling the relationship in Hypothesis 1.

A structural equation model was developed and estimated to validate (that is, establish the nature and strength of) the hypothesised model (Hypothesis 1) of the relationship between BIM implementation strategies (*Y*) and the level of BIM adoption on construction projects (*K*) (see Figure 5.6). The model hypothesised a positive relationship between these two constructs, which implies that the use of *Y1* will ensure *K1 – K5*, the use of *Y2* will ensure *K1*

– *K5*, and the use of *Y3* will ensure *K1 – K5*. It also implies that the use of *Y4* will ensure *K1 – K5*. The method of estimation for the structural equation model was the Maximum Likelihood Estimation method. The path diagram representing the model is shown in Figure 5.6.

In the path diagram, the main constructs are depicted with bigger cycles, while the sub-constructs are depicted with smaller cycles. BIM implementation strategies are denoted with *Y* representing the main construct and *Y1-Y4* as sub-constructs. The level of BIM adoption on construction projects is denoted with *K* representing the main construct and *K1-K5* representing the sub-constructs. Based on the result of the consistency and reliability tests reported in Table 5.29a – 5.29d, *Y1* was measured using 33 variables, *Y2* was measured using 36 variables, *Y3* using 14 variables, and *Y4* using 14 variables. As presented in Table 5.31a – 5.31e, *K1* was measured using 42 variables, *K2* using 5 variables, *K3* using 29 variables, *K4* using 19 variables, and *K5* using 4 variables.

The estimates for the model's parameters are presented in Table 5.34. Table 5.34 shows that the parameter estimates for all the hypothesized relationships are positive. This indicates that *Y* and *K* are positively associated. The relationship between *Y* and *Y2* has the weakest association at 0.59 positive correlation, closely followed by the relationship between *K* and *K2* with a 0.67 estimate (that is, 0.67 positive correlation). The relationship between *K* and *K5* has the strongest association at 1.18 positive correlation. The other hypothesised relationships with strongly positive correlations are *K* and *K3* (r = 1.07), *Y* and *Y1* (r = 1.03), and *Y* and *Y4* (r=1.16). At the recommended cut-off value of 0.50, the z-value for all the relationships, as shown in Table 5.34, was found to be significant. Table 5.35 presents the results of the validity of the model.

The fit indices, as shown by the results, are all above the recommended criteria [Chi square = 4020.57, df = 24, RMSEA = 0.048, TLI =0.977, CFI = 0.981, SRMR = 0.075]. The Chi-square test statistics are not significant at 0.05, which suggests that the model is acceptable. TLI and CFI for the model are above 0.97. This is a reflection of a good fit of the model. The RMSEA index is below 0.08, and the SRMR index is below 0.10, indicating that the model is a good fit. This good fit implies that the model is valid, and that the hypothesised model (Hypothesis 1) is appropriate to explain the relationship between BIM implementation strategies and the level of BIM adoption on construction projects.

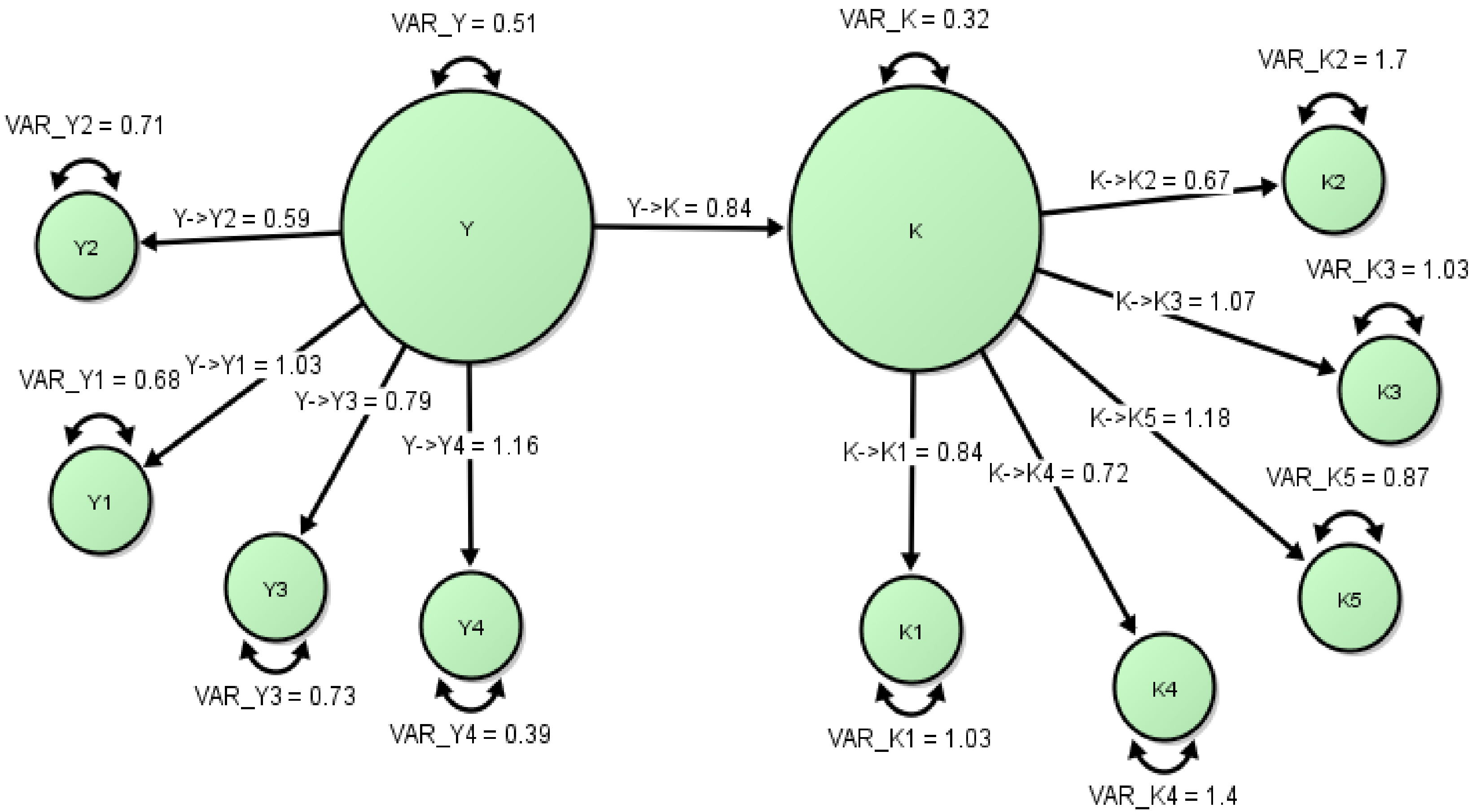

Figure 5.6: The path analysis diagram for the model of the relationship in Hypothesis 1.

[KEY: ***Y= BIM implementation strategies employed, K= Level of BIM application on construction projects, Y1= BIM motivations (employed), Y2=BIM commitments (employed), Y3=BIM capacity development (employed), Y4=BIM utilisation (employed), K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity].***

Table 5.34: Model estimation for the relationship in Hypothesis 1.

Relationships	Estimate	Standard Error	Z-value
K->K1	0.84	0.10	8.36
K->K2	0.67	0.08	8.37
K->K3	1.07	0.12	8.36
K->K4	0.72	0.08	8.36
K->K5	1.18	0.14	8.36
Y->K	0.84	0.12	6.53
Y->Y1	1.03	0.10	9.38
Y->Y2	0.59	0.06	9.37
Y->Y3	0.79	0.08	9.37
Y->Y4	1.16	0.12	9.36
Y= BIM implementation strategies employed, K= Level of BIM application on construction projects, Y1= BIM motivations (employed), Y2=BIM commitments (employed), Y3=BIM capacity development (employed), Y4=BIM utilisation (employed), K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity.			

Table 5.35: Fit indices for the estimated model of the relationship in Hypothesis 1.

Fit index	Values
Basic statistics	
Estimated parameters	21
Observed Statistics	45
Number of Observations	872
Restricted Degrees of Freedom	24
Degrees of Freedom (independent)	36
The goodness of fit index	
Model Chi-Square	4020.57
Chi-square from independent	297.186
RMSEA	0.048
SRMR	0.075
CFI	0.981
TLI	0.977

5.7.2 Modelling the relationship in Hypothesis 2.

Structural equation modeling, using Maximum Likelihood Estimate (MLE), was conducted to model (that is, validate the nature and strength of) the relationship between BIM implementation strategies and barriers against preliminary and sustained BIM adoption on construction projects (Hypothesis 2). The model hypothesised an inverse relationship between BIM implementation strategies (*Y*) and barriers against preliminary and sustained BIM adoption on a construction project (*P* and *S*). This means that increased use of BIM implementation strategies (*Y1*, *Y2*, *Y3*, and *Y4*) will bring about a decrease in the barriers against preliminary and sustained BIM adoption on construction projects. In the path diagram shown in Figures 5.7, there are three main constructs (depicted as bigger cycles) and four sub-constructs (depicted as small cycles).

For the main constructs, *Y* denotes BIM implementation strategies, with *Y1*, *Y2*, *Y3*, and *Y4* as sub-constructs. *P* denotes the barriers against preliminary BIM adoption and *S* denotes the barriers against sustained BIM adoption. Twenty-two (22) variables and 28 variables were used to measure *P* and *S* respectively (see Table 6.29a, 6.29b, 6.29c, 6.29d, 6.27 and 6.28). The model's parameters consist of six relationships ($Y \rightarrow P$, $Y \rightarrow S$, $Y \rightarrow Y1$, $Y \rightarrow Y2$, $Y \rightarrow Y3$, $Y \rightarrow Y4$), four (4) sub-constructs, and three constructs (see Figure 6.7). The relationships between *Y* and *P* (r = - 0.31, z = 1.37), as well as *Y* and S (r= -0.47, z= 2.91), have weak negative and significant correlation. This means that as *Y* increases, *S* and *P* decrease.

This confirms the hypothesis that as the use of BIM implementation strategies increases, there is a corresponding decrease in the barriers against preliminary and sustained BIM adoption on construction projects. For the sub-constructs, the results show that there is a strong positive and significant correlation between *Y* and *Y1* (r = 1.37, z =3.05) and *Y* and *Y4* (r = 1.20, z = 3.71). A moderately positive and significant association exists between *Y* and *Y1* (r= 0.79, z=6.06) and *Y* and *Y3* (r= 0.74, z=5.97). The fit indices for the estimated model are all above the recommended criteria, as shown in Table 6.37 [Chi square = 2291.54, df = 17, RMSEA = 0.077, TLI = 0.991, CFI = 0.976, SRMR = 0.092]. The model is acceptable because the Chi-square statistics are not significant at 0.05. The model is also acceptable because TLI and CFI are above 0.97, the RMSEA index is below 0.08, and the SRMR index is below 0.10. These results imply that the model (Hypothesis 2) of the inverse relationship between BIM implementation strategies and the barriers against preliminary and sustained BIM adoption on construction projects is valid.

Hypothesis 2 theorises that the use of BIM implementation strategies will cause a reduction in the barriers against preliminary and sustained BIM adoption on construction projects. The validity of the structural equation model that was tested in Figure 5.7 provides support for this theory.

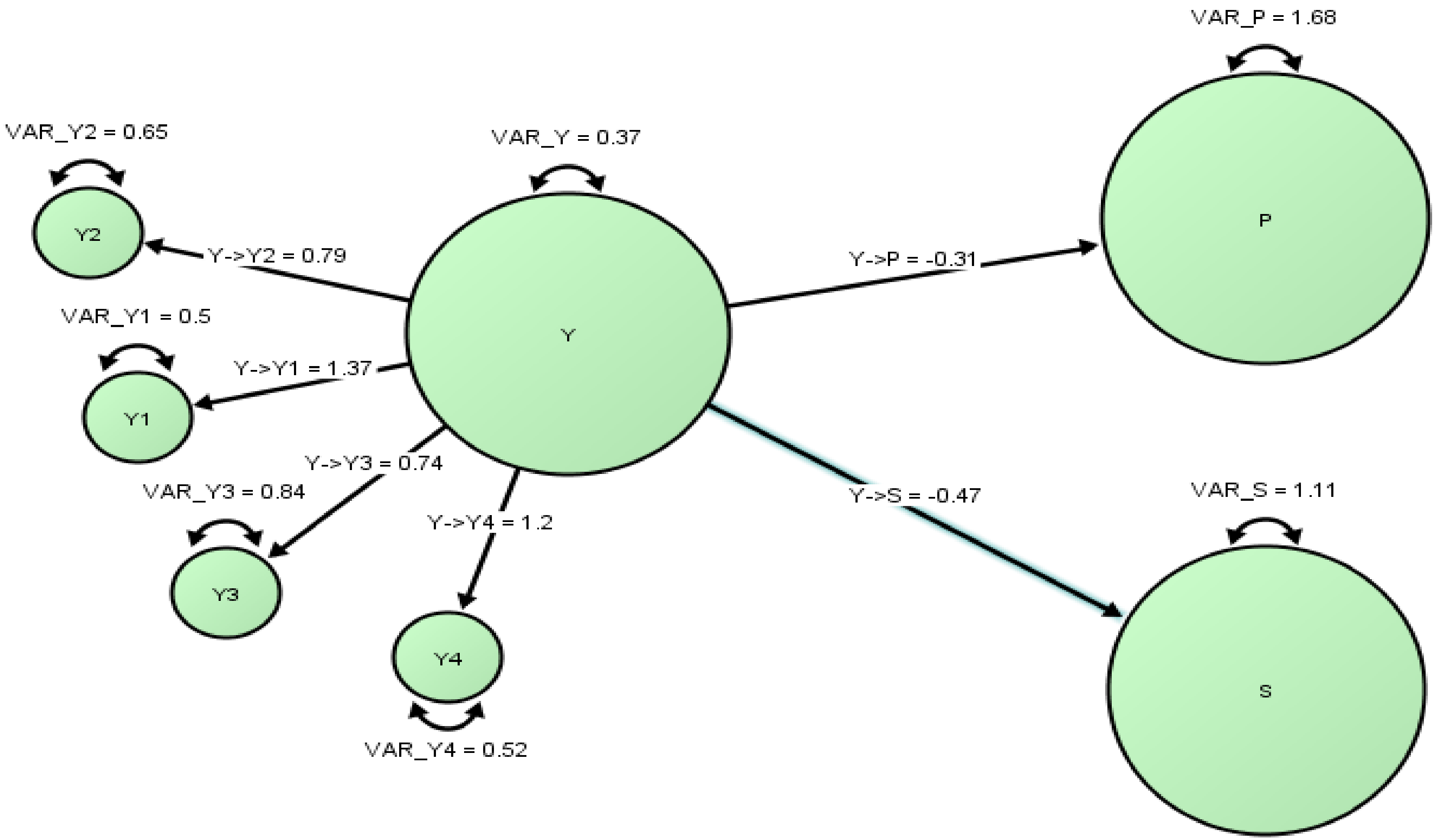

Figure 5.7: The path analysis diagram for the model of the relationship in Hypothesis 2.

[KEY: ***Y= BIM implementation strategies employed, P= barriers against preliminary BIM adoption, S= barriers against sustained BIM adoption, Y1= BIM motivations (employed), Y2=BIM commitments (employed), Y3=BIM capacity development (employed), Y4=BIM utilisation (employed)].***

Table 5.36: Model estimation for the relationship in Hypothesis 2.

Relationships	Estimate	Standard Error	Z-value
Y->P	- 0.31	1.22	1.37
Y->S	- 0.47	0.16	2.91
Y->Y1	1.37	0.44	3.05
Y->Y2	0.79	0.13	6.06
Y->Y3	0.74	0.12	5.97
Y->Y4	1.20	0.32	3.71
Y= BIM implementation strategies employed, P= barriers against preliminary BIM adoption, S= barriers against sustained BIM adoption, Y1= BIM motivations (employed), Y2=BIM commitments (employed), Y3=BIM capacity development (employed), Y4=BIM utilisation (employed).			

Table 5.37: Fit indices for the estimated model of the relationship in Hypothesis 2.

Fit index	Values
Basic statistics	
Estimated parameters	19
Observed Statistics	36
Number of Observations	872
Restricted Degrees of Freedom	17
Degrees of Freedom (independent)	28
The goodness of fit index	
Model Chi-Square	2291.54
Chi-square from independent	405.118
RMSEA	0.077
SRMR	0.092
CFI	0.976
TLI	0.991

5.7.3 Modelling the relationship in Hypothesis 5.

A structural equation model was estimated to model (that is, establish the nature and strength of) the effects of a reduction in barriers against preliminary and sustained BIM adoption on the level of BIM adoption on construction projects (Hypothesis 5). The model hypothesised that a significant reduction in barriers against preliminary and sustained BIM adoption (*M*) has a positive significant impact on the level of BIM adoption on construction projects (*K*). This means that as the rate of reduction of the barriers against preliminary and sustained BIM adoption increase, the extent of usage of *K1, K2, K3, K4*, and *K5* on construction projects increases. The path diagram for the model features two main constructs (*M* and *K*) and five sub-constructs (*K1, K2, K3, K4*, and *K5*) (see Figure 5.8). The measurement models entail 42 variables for *K1*, five variables for *K2*, 17 variables for *K4*, and four variables for *K5* (Table 5.30 and Table 5.31a – 5.31e).

As presented in Table 5.38, there is a weakly positive and significant association (r = 0.09, z = 3.41) between *M* and *K*. The construct *K* shares a strongly positive and significant association with sub-construct *K1* (r = 1.09, z = 3.10), and sub-construct *K3* (r = 1.46, z = 5.16). With sub-construct *K2* (r = 0.93, z = 3.99) and sub-construct *K4* (r = 0.94, z = 2.04), *K* shares a moderately positive and significant association. Table 5.39 shows that the fit indices for the estimated model are all above the recommended criteria [Chi-square = 3210.89, df = 8, RMSEA = 0.001, TIL=0.980, CFI = 0.979, SRMR = 0.078]. This result reflects a good fit of the model, since the Chi-square statistics are not significant at 0.05, TLI and CFI are above 0.97, the RMSEA index is below 0.08, and the SRMR index is below 0.10. This result validates the hypothesis (Hypothesis 5) that a reduction in barriers against preliminary and sustained BIM adoption has a positive, significant impact on the level of BIM adoption on construction projects.

Hypothesis 5 theorises that a surge in the rate by which the barriers against preliminary and sustained BIM adoption decrease will increase the extent to which BIM is adopted on construction projects. The hypothesis was validated by the results of the structural equation model in Figure 5.8, Table 5.38, and Table 5.39.

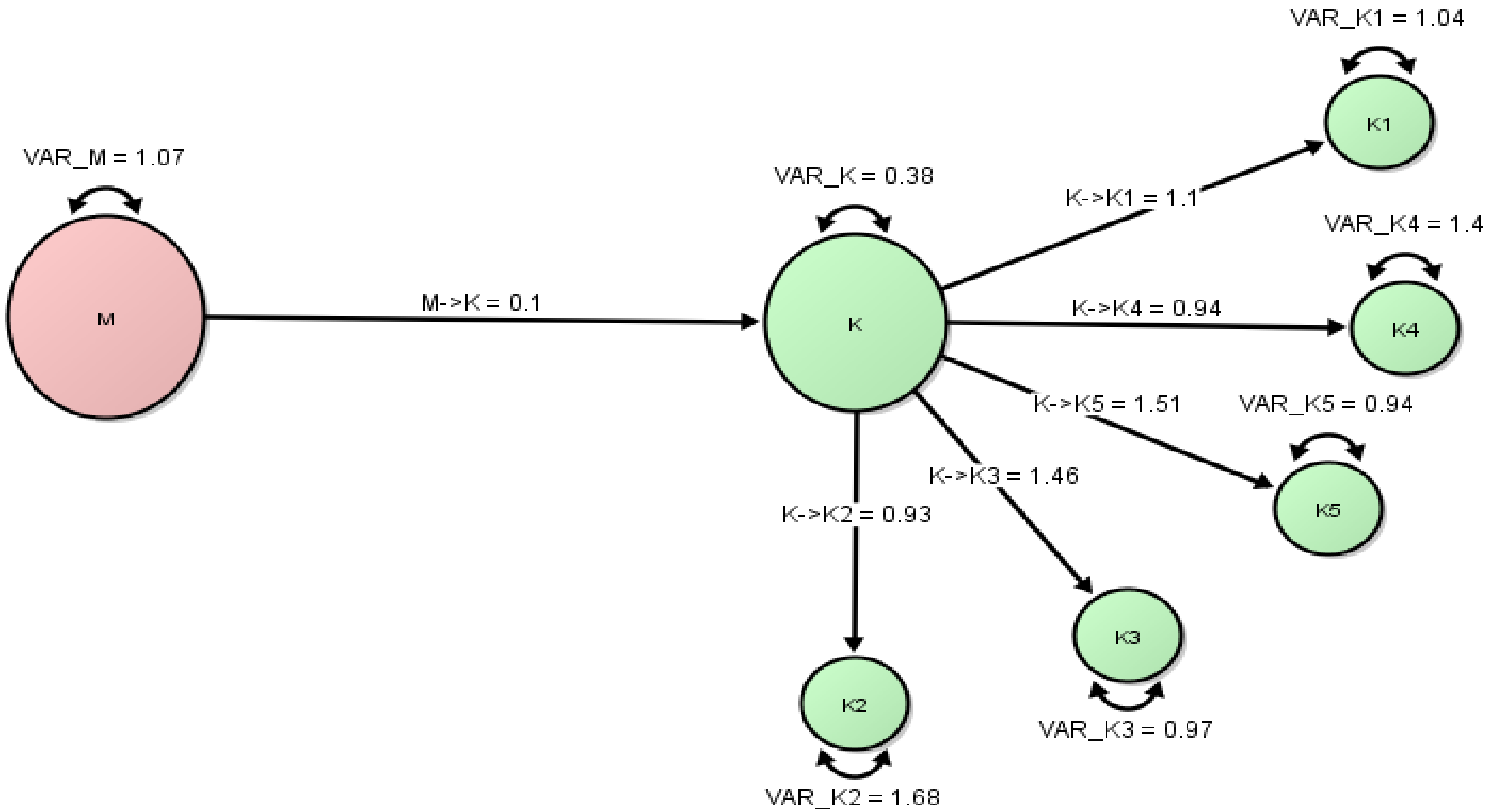

Figure 5.8: The path analysis diagram for the model of the relationship in Hypothesis 5.

[KEY: K= Level of BIM application on construction projects, M= Indicators of reduction in barriers against preliminary and sustained BIM adoption, K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity].

Table 5.38: Model estimation for the relationship in Hypothesis 5.

Relationships	Estimate	Standard Error	Z-value
K->K1	1.09	0.35	3.10
K->K2	0.93	0.23	3.99
K->K3	1.46	0.28	5.16
K->K4	0.94	0.46	2.04
K->K5	1.51	0.22	6.66
M->K	0.09	0.02	3.41
K= Level of BIM application on construction projects, M= Indicators of reduction in barriers against preliminary and sustained BIM adoption, K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity.			

Table 5.39: Fit indices for the estimated model of the relationship in Hypothesis 5.

Fit index	Values
Basic statistics	
Estimated parameters	13
Observed Statistics	21
Number of Observations	872
Restricted Degrees of Freedom	8
Degrees of Freedom (independent)	15
The goodness of fit index	
Model Chi-Square	3210.89
Chi-square from independent	162.638
RMSEA	0.001
SRMR	0.078
CFI	0.979
TLI	0.980

5.7.4 Modelling the relationships in Hypothesis 3.

A structural equation model was conducted to model (that is, validate the nature and strength of) the relationship between BIM implementation strategies (*Y*), a reduction in barriers against preliminary and sustained BIM adaptation (*M*), and the level of BIM adoption on construction projects (*K*). The model hypothesised (Hypothesis 3) that the positive relationship between BIM implementation strategies and the level of BIM adoption on construction projects is mediated by a reduction in barriers against preliminary and sustained BIM adoption. This indicates that a reduction in barriers against preliminary and sustained BIM adoption plays a positive and significant role in the decisions by organisations and professionals to adopt BIM on construction projects by using the BIM implementation strategies already in place. As illustrated in the path analysis diagram for the model (Figure

5.9), the model features three main constructs (*Y*, *K*, and *M*) and nine sub-constructs (*Y1*, *Y2*, *Y3*, *Y4*, *K1*, *K2*, *K3*, *K4*, and *K5*).

Each of these sub-constructs was measured using their respective measurement models as validated in Table 5.29a – 5.29d, Table 5.30, and Table 5.31a – 5.31e. The results of the model estimation are presented in Table 5.40. *Y* and *M* were found to have a positive and significant effect on *K*. The relationship between *M* and *K* was strongly positive and significant (r = 1.03, z = 2.08), the correlation between *Y* and K was weakly positive and significant (r = 0.17, z = 8.85), and the relationship between *Y* and *M* was moderately positive and significant (r = 0.83, z = 5.17). This shows that a significant reduction in BIM adoption barriers will increase the use of BIM implementation strategies and indirectly increase the adoption of BIM on construction projects. The association between *K* and its sub-constructs was moderately positive and significant (see Table 5.40).

Similarly, *Y* has a moderately positive and significant relationship with its sub-constructs (see Table 5.40). The results of the fit indices for the estimated model are presented in Table 5.41. The fit indices are within the recommended value [Chi square = 4307.68, df =29, RMSEA = 0.050, SRMR = 0.087, CFI = 0.977, TLI = 0.973]. This result is a reflection of a good fit of the model, because the Chi-square test statistics are not significant at 0.05, TLI and CFI for the model are above 0.97, RMSEA index is below 0.08, and SRMR index is below 0.10. This result indicates that a significant reduction in barriers against preliminary and sustained BIM adoption plays a positive and significant role in the relationship between BIM implementation strategies and the level of BIM adoption on construction projects. This means that Hypothesis 3 is valid and fully supported.

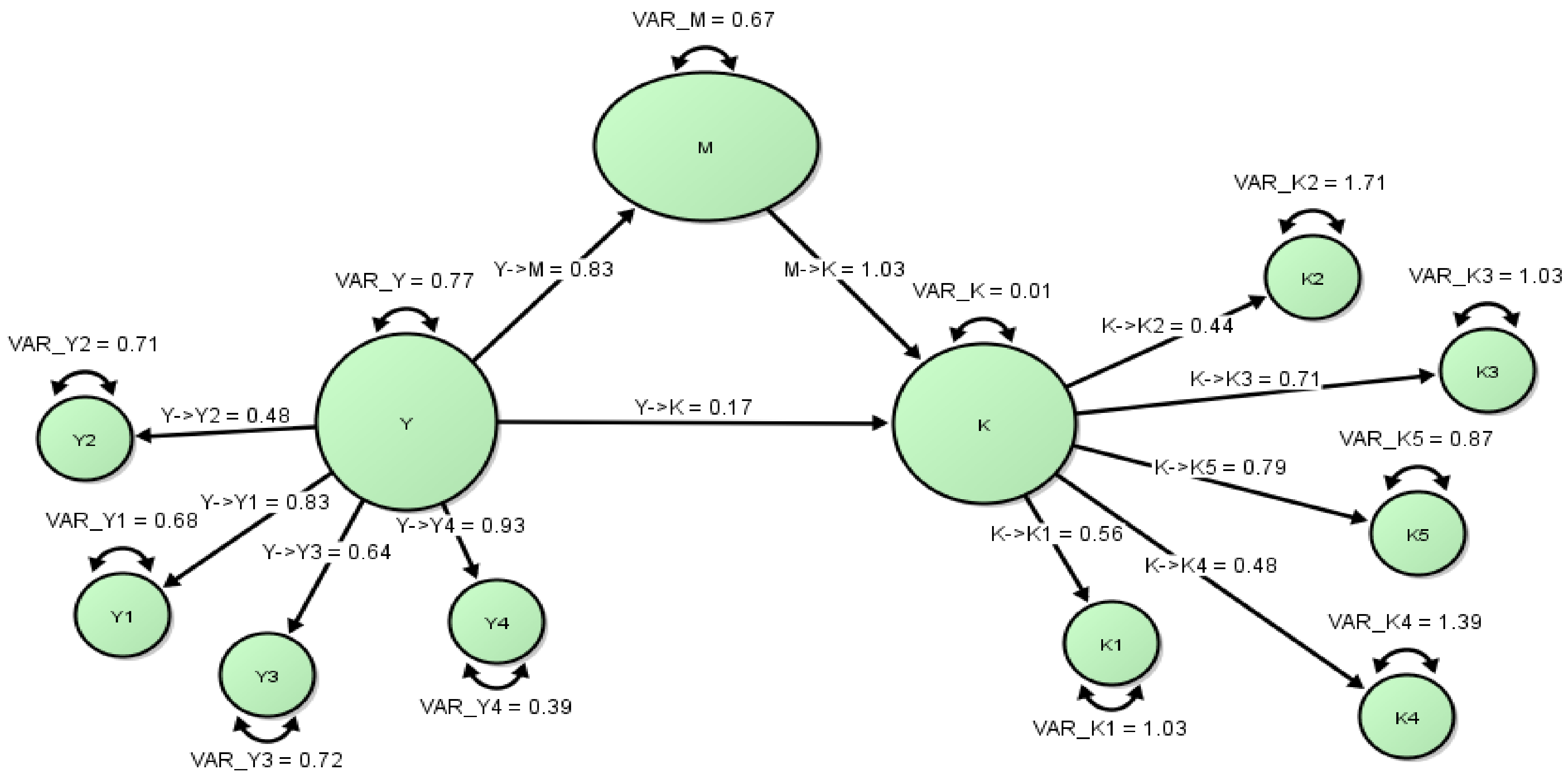

Figure 5.9: The path analysis diagram for the model of the relationship in Hypothesis 3.

[KEY: Y= BIM implementation strategies employed, K= Level of BIM application on construction projects, M= Indicators of reduction in barriers against preliminary and sustained BIM adoption, Y1= BIM motivations (employed), Y2=BIM commitments (employed), Y3=BIM capacity development (employed), Y4=BIM utilisation (employed), K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity].

Table 5.40: Model estimation for the relationship in Hypothesis 3.

Relationships	Estimate	Standard Error	Z-value
K->K1	0.55	0.05	9.43
K->K2	0.43	0.09	4.38
K->K3	0.70	0.18	3.82
K->K4	0.47	0.17	2.66
K->K5	0.78	0.18	4.22
M->K	1.03	0.49	2.08
Y->K	0.17	0.02	8.85
Y->M	0.83	0.15	5.71
Y->Y1	0.83	0.72	1.15
Y->Y2	0.48	0.09	5.33
Y->Y3	0.64	0.19	3.31
Y->Y4	0.93	0.89	1.04
Y= BIM implementation strategies employed, K= Level of BIM application on construction projects, M= Indicators of reduction in barriers against preliminary and sustained BIM adoption, Y1= BIM motivations (employed), Y2=BIM commitments (employed), Y3=BIM capacity development (employed), Y4=BIM utilisation (employed), K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity.			

Table 5.41: Fit indices for the estimated model of the relationship in Hypothesis 3.

Fit index	Values
Basic statistics	
Estimated parameters	26
Observed Statistics	55
Number of Observations	872
Restricted Degrees of Freedom	29
Degrees of Freedom (independent)	45
The goodness of fit index	
Model Chi-Square	4307.68
Chi-square from independent	320.099
RMSEA	0.050
SRMR	0.087
CFI	0.977
TLI	0.973

5.7.5 Modelling the relationship in Hypothesis 4.

A structural equation model (SEM) was created to analyse the effects that the level of BIM adoption on construction projects had on the levels of integration and collaboration among the BIM-SCM. The SEM hypothesised (Hypothesis 4) that there is a positive and significant relationship between the level of BIM adoption on construction projects (*K*) and the levels of integration and collaboration among the BIM-SCM (*Z*). This hypothesis suggests that the occurrence of collaborative features, such as cooperation, teamwork, open communication, and shared interests, among the BBCPs participants depends on the application of BIM tools, processes, and principles on construction projects. Figure 6.10 shows the path diagram for the SEM.

In the Figure, *K* symbolizes the level of BIM adoption on construction projects, and it has five sub-constructs (*K1, K2, K3, K4*, and *K5*). *Z* signifies the levels of integration and collaboration among the BIM-SCM, and has four sub-constructs (*Z1, Z2, Z3*, and *Z4*). The model's parameters consist of ten relationships ($K \rightarrow K1$, $K \rightarrow K2$, $K \rightarrow K3$, $K \rightarrow K4$, $K \rightarrow K5$, $K \rightarrow Z$, $Z \rightarrow Z1$, $Z \rightarrow Z2$, $Z \rightarrow Z3$, and $Z \rightarrow Z4$). The measurement models for *K* and its sub-constructs entail 42 variables for *K1*, 5 variables for *K2*, 17 variables for *K3*, 17 variables for K4, and 4 variables for *K5* (see Table 5.31a – 5.31e). The variables for measuring *Z* and its sub-constructs are presented in Table 5.32a – 5.32d. The estimation for SEM, as shown in Table 5.42, revealed that there is a moderately positive association between *K* and *K2* (r=0.64, z=9.03), *K* and *K3* (r=0.99, z=7.35), and *K* and *K4* (r=0.91, z=7.97).

The relationships between *K* and *Z* (r=1.29, z=6.00), and *K* and *K1* (r=1.07, z=6.22) are strongly positive. A strong and positive association between *K* and *Z* confirms the hypothesis in the SEM, and indicates that the level of BIM adoption on construction projects has a positive and significant effect on the levels of integration and collaboration among the BIM-SCM. Also, there is a moderately positive correlation between *Z* and *Z1* (r=0.68, z=6.00), *Z* and *Z2* (r=0.80, z=5.17), *Z* and *Z3* (r=0.69, z=5.89), and *Z* and *Z4* (r=0.66, z=6.28). Table 5.43 presents the fit indices for validating the parameter estimates in the SEM. As shown in the Table, the fit indices for the estimated model are all above the recommended criteria [Chi-square= 4170.77, df=24, RMSEA=0.044, SRMR=0.066, CFI=0.988, TLI = 0.983]. These results validate the SEM and show that the hypothesis is acceptable. This validation is based on the fact that the Chi-square statistics are not significant at 0.05, the TLI and CFI are above 0.97, the RMSEA index is below 0.08, and SRMR index is below 0.10. The validity of the SEM implies that, as the use of BIM tools and principles on construction projects increases, there will be a corresponding increase in the occurrence of network communication, information sharing and exchange, knowledge sharing and transfer, and network communication among the BIM-SCM. This means that the parameters of the structural equation model that was tested fully substantiated Hypothesis 4.

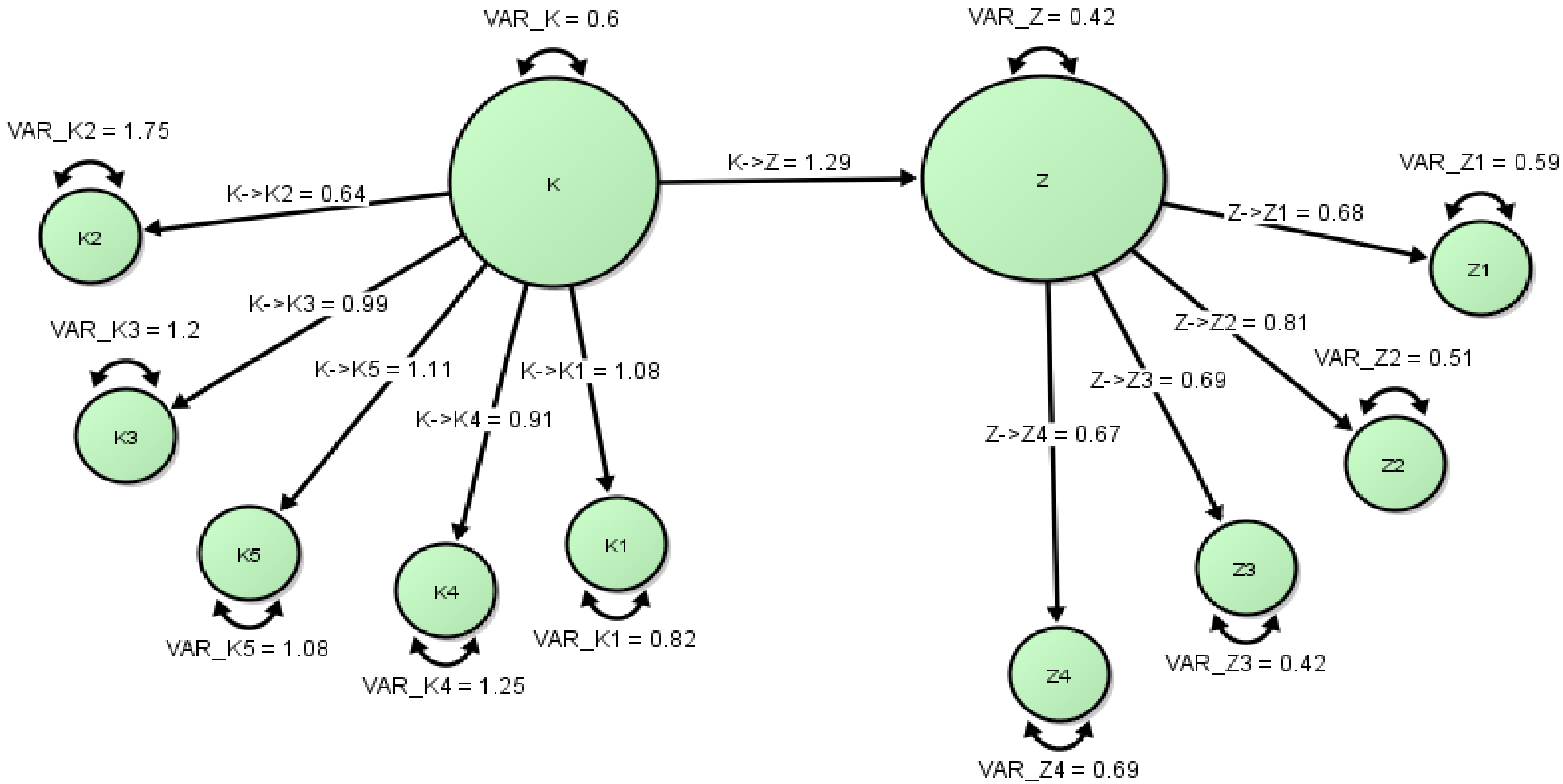

Figure 5.10: The path analysis diagram for the model of the relationship in Hypothesis 4.

[KEY: K= Level of BIM application on construction projects, Z= Levels of integration and collaboration among the BIM supply chain members, K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity, Z1= Trust-based relationships, Z2= Information sharing and exchange, Z3= Network communication, Z4= Knowledge sharing and transfer].

Table 5.42: Model estimation for the relationship in Hypothesis 4.

Relationships	Estimate	Standard Error	Z-value
K->K1	1.07	0.17	6.22
K->K2	0.64	0.07	9.03
K->K3	0.99	0.13	7.35
K->K4	0.91	0.11	7.97
K->K5	1.11	0.16	6.84
K->Z	1.29	0.22	6.00
Z->Z	0.68	0.11	6.00
Z->Z2	0.80	0.15	5.17
Z->Z3	0.69	0.11	5.89
Z->Z4	0.66	0.10	6.28

K= Level of BIM application on construction projects, Z= Levels of integration and collaboration among the BIM supply chain members, K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity, Z1= Trust-based relationships, Z2= Information sharing and exchange, Z3= Network communication, Z4= Knowledge sharing and transfer.

Table 5.43: Fit indices for the estimated model of the relationship in Hypothesis 4.

Fit index	Values
Basic statistics	
Estimated parameters	21
Observed Statistics	45
Number of Observations	872
Restricted Degrees of Freedom	24
Degrees of Freedom (independent)	36
The goodness of fit index	
Model Chi-Square	4170.77
Chi-square from independent	396.464
RMSEA	0.044
SRMR	0.066
CFI	0.988
TLI	0.983

5.7.6 The model of the interactions in Hypothesis 6a and 6b.

The structural equation model testing Hypothesis 6a and 6b was developed using two sets of BIM implementation strategies –

(a) The BIM implementation strategies that are employed to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects (see Figure 5.11, Table 5.44, and Table 5.45).

(b) The BIM implementation strategies that are required to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects (see Figure 5.12, Table 5.46, and Table 5.47).

A structural equation model (using the Maximum Likelihood method of estimation) was estimated for the model of the interactions (that is, to determine the nature and strength of interactions) between the levels of integration and collaboration among the BIM supply chain member (*Z*), the level of BIM adoption on construction projects (*K*), reduction in barriers against preliminary and sustained BIM adoption on a construction project (*M*), and BIM implementation strategies that are employed to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects (*Y*). The model hypothesises that the BIM implementation strategies in use will cause a significant reduction in BIM adoption barriers. The model further posits that a widespread BIM adoption on construction projects will take place as a result of a significant reduction in BIM adoption barriers. The model projects that a significant level of integration and collaboration will occur among the BIM supply chain members (construction organisations and professionals) as a result of the widespread adoption of BIM tools, principles, and processes on construction projects.

The path analysis diagram for the model is shown in Figure 5.11. The measurement models for constructs and sub-constructs are explained in Table 5.29a – Table 5.29d, Table 5.30, Table 5.31a – Table 5.31e, and (Table 5.32a – Table 5.32d). The model estimation for the structural equation model, as shown in Table 5.44, revealed a positive interaction between the constructs. The model estimation shows that there

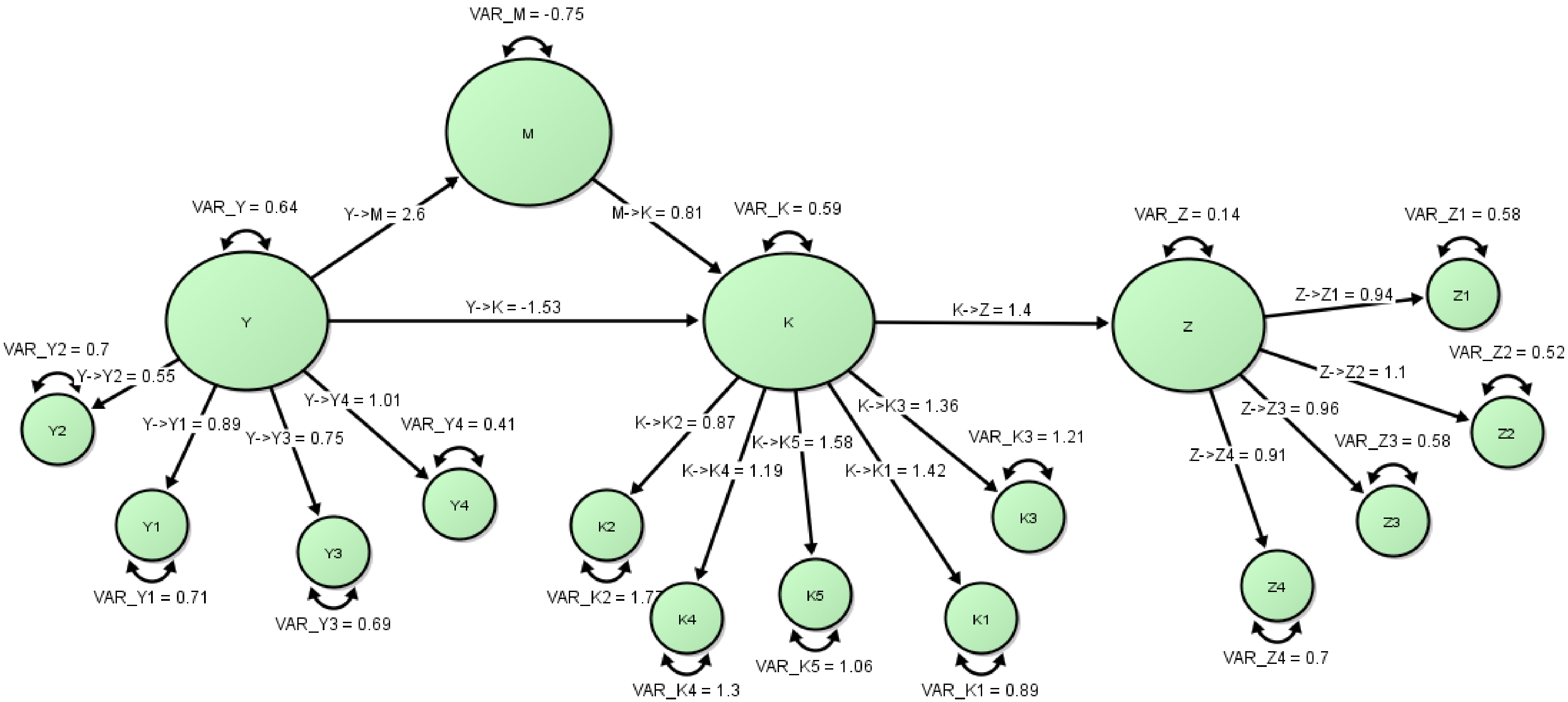

Figure 5.11: The path analysis diagram for the model of the interactions in Hypothesis 6a.

[KEY: ***Y= BIM implementation strategies employed, K= Level of BIM application on construction projects, M= Indicators of reduction in barriers against preliminary and sustained BIM adoption, Z= Levels of integration and collaboration among the BIM supply chain members, Y1= BIM motivations (employed), Y2=BIM commitments (employed), Y3=BIM capacity development (employed), Y4=BIM utilisation (employed), K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity, Z1= Trust-based relationships, Z2= Information sharing and exchange, Z3= Network communication, Z4= Knowledge sharing and transfer].***

is a very strong, positive, and significant association between Y and M (r=2.59, z=6.41), and a strong, positive, and significant relationship between *K* and *Z* (r=1.40, z=6.15), and *Y* and *K* (r=1.53, z=5.96). The relationship between *M* and *K* was found to be moderately positive and significant (r=0.80, z=5.88). The nature and strength of interactions between *Y, M, K,* and *Z* indicate that they are all positively related and that the relationship is strong. This is a confirmation of the hypothesis in the structural equation model.

Table 5.44: Model estimation for the interactions in Hypothesis 6a.

Relationships	Estimate	Standard Error	Z-value
K->K1	1.42	0.19	7.15
K->K2	0.86	0.09	9.14
K->K3	1.35	0.17	7.91
K->K4	1.19	0.14	8.42
K->K5	1.57	0.22	7.06
K->Z	1.40	0.22	6.15
M->K	0.80	0.13	5.88
Y->K	1.53	0.25	5.96
Y->M	2.59	0.40	6.41
Y->Y1	0.89	0.15	5.88
Y->Y2	0.55	0.08	6.62
Y->Y3	0.75	0.12	6.15
Y->Y4	1.01	0.24	4.20
Z->Z1	0.94	0.15	6.10
Z->Z2	1.10	0.20	5.43
Z->Z3	0.96	0.16	5.96
Z->Z4	0.91	0.14	6.41

***: Y= BIM implementation strategies employed, K= Level of BIM application on construction projects, M= Indicators of reduction in barriers against preliminary and sustained BIM adoption, Z= Levels of integration and collaboration among the BIM supply chain members, Y1= BIM motivations (employed), Y2=BIM commitments (employed), Y3=BIM capacity development (employed), Y4=BIM utilisation (employed), K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity, Z1= Trust-based relationships, Z2= Information sharing and exchange, Z3= Network communication, Z4= Knowledge sharing and transfer*.**

It was found that construct K has a moderately positive and significant relationship with K2 (r=0.86, z=9.14), and a strongly positive and significant relationship with K1 (r=1.42, z=7.15), K3 (r=1.35, z=7.91), K4 (r=1.19, z=8.42), and K5 (r=1.57, z=7.06). Also, it was found that construct Y has a moderately positive and significant relationship with Y1 (r = 0.89, z =5.88), Y2 (r = 0.55, z = 6.62), and Y3 (r=0.75, z=6.15). The relationship between Y and Y4 is strongly positive and significant (r = 1.01, z = 4.20). There is a moderately positive and significant relationship between Z and Z1 (r = 0.94, z = 6.10), Z and Z3 (r = 0.96, z =5.96), and Z and Z4 (r = 0.91, z = 6.41). The relationship between Z and Z2 is strongly positive and significant (r = 1.10, z =5.43).

The results suggest that the correlation between the constructs and their sub-constructs is acceptable. The fit indices for the estimated model of the interaction between Y, M, K, and Z are presented in Table 5.45. The fit indices are not beyond the limits of the recommended values [Chi-square= 5528.82, df=69, RMSEA=0.030, SRMR=0.073, CFI=0.984, TLI = 0.975]. These indices imply that the model is a good fit, since the Chi-square test statistics are not significant at 0.05, TLI and CFL for the model are above 0.97, the RMSEA index is below 0.08, and SRMR index is below 0.10. These results show that the model is valid and that there is a positive and significant interaction between Y, M, K, and Z.

Table 5.45: Fit indices for the estimated model of the interactions in Hypothesis 6a.

Fit index	**Values**
Basic statistics	
Estimated parameters	36
Observed Statistics	105
Number of Observations	872
Restricted Degrees of Freedom	69
Degrees of Freedom (independent)	91
The goodness of fit index	
Model Chi-Square	5528.82
Chi-square from independent	610.499
RMSEA	0.030
SRMR	0.073
CFI	0.984
TLI	0.975

A structural equation model (using the Maximum Likelihood method of estimation) was estimated for the model of the interactions between the levels of integration and collaboration among the BIM supply chain member (*Z*), the level of BIM adoption on construction projects (*K*), reduction in barriers against preliminary and sustained BIM adoption on a construction project (*M*) and the BIM implementation strategies that are required to trigger a reduction in the barriers against preliminary and sustained BIM adoption on construction projects (*X*). The model explains that certain BIM implementation strategies are presently not in use, but that their usage will cause a significant reduction in BIM adoption barriers. The model further explains that a widespread BIM adoption on construction projects will take place as a result of a significant reduction in BIM adoption barriers.

The model projects that a significant level of integration and collaboration will occur among the BIM supply chain members (construction organisations and professionals) as a result of the widespread adoption of BIM tools, principles, and processes on construction projects.

Figure 5.12 shows the path analysis diagram for the model. The sub-construct *X1* was measured using 36 variables, *X2* was measured using 32 variables, *X3* was measured using 14 variables, and X4 was measured using 13 variables (see Table 5.33a – 5.33d). Table 5.46 presents the model estimation for the strength, type, and significance of the relationships between the main constructs and their sub-constructs. Table 5.46 shows a positive and significant interaction between *K, Z, X,* and *M*. Table 5.46 also shows that there is a strongly positive and significant association between *K* and *Z* (r = 1.03, z = 4.53) as well as *K* and *X* (r = 1.77, z = 2.39). Construct *K* has a moderately positive but significant relationship with *M* (r =0.87, z =2.98).

The relationship between *X* and *M* was found to be very strong, positive, and significant (r=2.31, z=4.87). The correlations between *K, Z,* and *X*, and their sub-constructs are moderate, positive, and significant (see Table 5.46). The results of the fit indices for the estimated model are presented in Table 5.47. The fit indices are within the limits of the recommended values [Chi-square = 5296.01, df = 69, RMSEA = 0.030, SRMR = 0.075, CFI = 0.987, TLI =0.983]. This result is a confirmation of the good fit of the model, because the SRMR index is below 0.10, TLI and CFI are above 0.97, RMSEA index is below 0.08, and the Chi-square test statistics is not significant at 0.05. This result validates the model and indicates that there is a positive and significant interaction between *X, M, K,* and *Z.*

The proposition in Hypothesis 6b advanced that there is a positive interdependence among the various BIM implementation stages. The hypothesis was tested in two situations, as explained in Figure 5.11, Table 5.44, Table 5.45, Figure 5.12, Table 5.46, and Table 5.47. In both situations, the hypothesis was fully supported by the parameter estimates in the structural equation model. In section 1.8, this research proposed that the *levels of integration and collaboration among BIM supply chain members are mediated by BIM adoption on construction projects through BIM implementation strategies that incorporate considerations for barriers against preliminary and sustained BIM adoption, a multi-dimensional approach,*

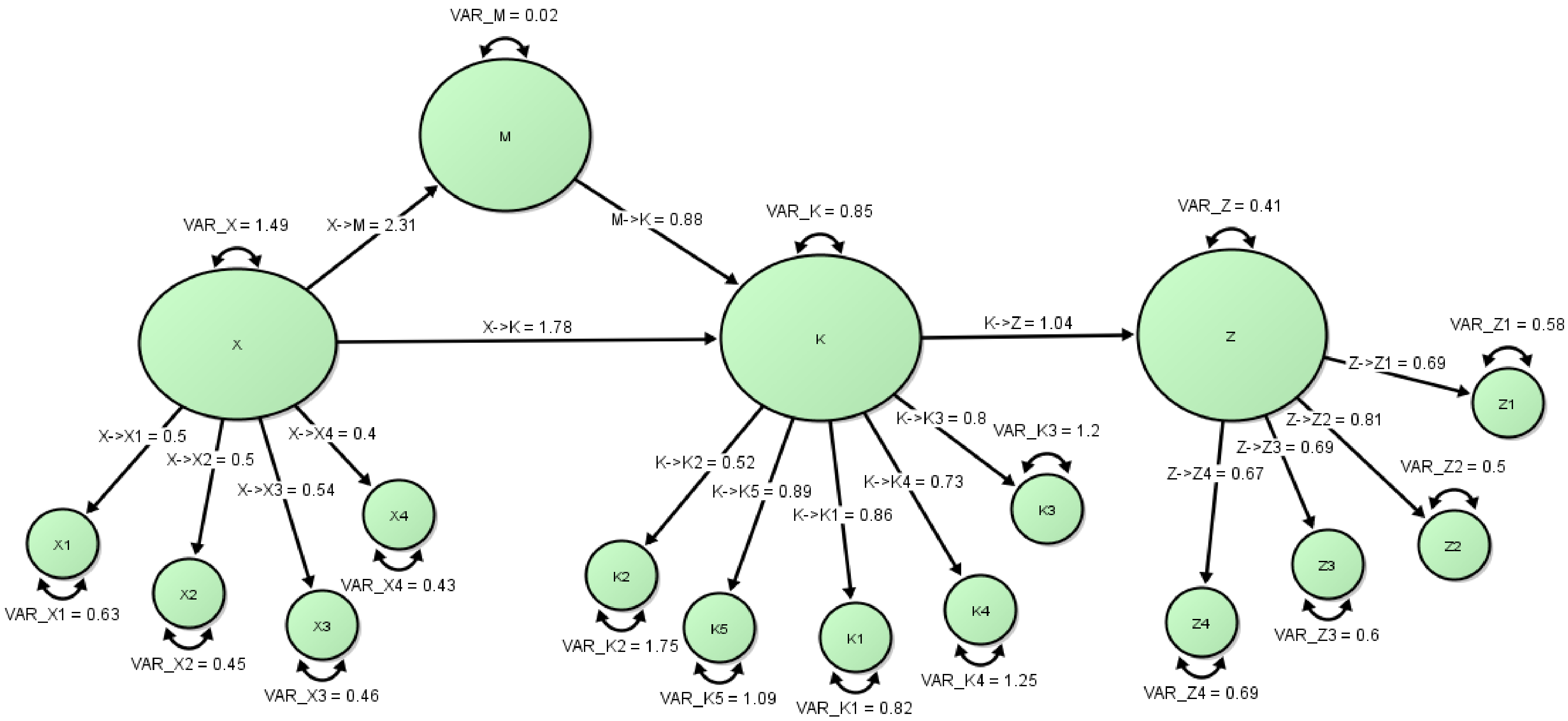

Figure 5.12: The path analysis diagram for the model of the interactions in Hypothesis 6b.

[KEY: X= BIM implementation strategies required, K= Level of BIM application on construction projects, M= Indicators of reduction in barriers against preliminary and sustained BIM adoption, Z= Levels of integration and collaboration among the BIM supply chain members, X1=BIM motivations (required), X2=BIM commitments (required), X3=BIM capacity development (required), X4=BIM utilisation (required), K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity, Z1= Trust-based relationships, Z2= Information sharing and exchange, Z3= Network communication, Z4= Knowledge sharing and transfer].

*and a strategic use of BIM on construction projects***.** This proposition was validated by the results of the structural equation model in this section. The validity of this proposition means that group effort, teamwork, and cooperation will occur among the construction professionals and subcontractors that are participating in BIM-based construction projects through the use of BIM implementation strategies that cause a reduction in BIM adoption barriers, together with a widespread and strategic BIM adoption on construction projects.

Table 5.46: Model estimation for the model of the interactions in Hypothesis 6b.

Relationships	Estimate	Standard Error	Z-value
K->K1	0.85	0.13	6.30
K->K2	0.51	0.05	9.03
K->K3	0.79	0.10	7.35
K->K4	0.72	0.08	8.01
K->K5	0.89	0.12	6.90
K->Z	1.03	0.22	4.53
M->K	0.87	0.29	2.98
X->K	1.77	0.74	2.39
X->M	2.31	0.47	4.87
X->X1	0.49	0.10	4.79
X->X2	0.50	0.10	4.91
X->X3	0.54	0.10	4.99
X->X4	0.40	0.07	5.29
Z->Z1	0.68	0.11	6.00
Z->Z2	0.80	0.15	5.16
Z->Z3	0.69	0.11	5.92
Z->Z4	0.66	0.10	6.29

X= BIM implementation strategies required, K= Level of BIM application on construction projects, M= Indicators of reduction in barriers against preliminary and sustained BIM adoption, Z= Levels of integration and collaboration among the BIM supply chain members, X1=BIM motivations (required), X2=BIM commitments (required), X3=BIM capacity development (required), X4=BIM utilisation (required), K1= BIM performance assessment criteria, K2= BIM capacity (skills and competencies), K3= BIM tools, K4= Types of building information models, K5= Level of objects' clarity, Z1= Trust-based relationships, Z2= Information sharing and exchange, Z3= Network communication, Z4= Knowledge sharing and transfer.

Table 5.47: Fit indices for the estimated model of the interactions in Hypothesis 6b.

Fit index	Values
Basic statistics	
Estimated parameters	36
Observed Statistics	105
Number of Observations	872
Restricted Degrees of Freedom	69
Degrees of Freedom (independent)	91
The goodness of fit index	
Model Chi-Square	5296.01
Chi-square from independent	538.635
RMSEA	0.030
SRMR	0.075
CFI	0.987
TLI	0.983

5.8 Summary of data analysis and results

The mean item score analysis showed that coordination of the BIM process in the organisations, education of staff members on the potentials of BIM, the introduction of collaborative teamwork culture in the organisation, self-initiated BIM training, on-the-job BIM training for the employees, determining the appropriate form of collaboration required for the project, determining the appropriate import and export file format for the project, and determining the appropriate intensity of collaboration required for the project are some of the significant BIM implementation strategies employed for driving BIM adoption on construction projects.

Information on the profiles of the BBCPs showed that the majority of the BBCPs are buildings for domestic use, road projects, commercial buildings, institutional buildings, and industrial buildings. Private clients and provincial departments are the clients for most of these projects, and the project team mostly bears the cost of BIM adoption on the BBCPs. The assessment of the pattern of BIM adoption on the BBCPs showed that Revit and ArchiCAD were the most predominant BIM software technologies utilized for the BBCPs. The BIM supply chain for the projects did not usually include the suppliers and subcontractors. BIM-friendly conventional procurement systems were favoured over integrated project delivery. The CAD experience and competence of the BIM supply chain were much pronounced in the BIM capacity that was employed for the BIM-based construction projects. Also, the pattern of BIM adoption on the BBCPs indicated that the BIM adoption plans for the BIM-based construction projects articulated the service requirements and design details and specifications as revealed by the level of development employed for the projects. The analysis of the complexity of the BBCPs showed that project milestones and deadline, construction technologies and systems, political and cultural sensitivity of projects, and regulatory requirements were incorporated into the evaluation of project complexity for BIM adoption. It was found that the project expectations from the BBCPs were based on the integrated expectation of the clients, projects, and participants.

The objective of the analysis of the measurement models was to examine the reliability, validity, and consistency of the measured variables (measurement models) that characterise the constructs required to develop the structural equation models for the structural equation modelling process. The homogeneity validity test, convergent validity test, significance test, reliability test, dimensionality test, internal consistency test, and discriminant validity test were conducted to confirm if the measured variables are adequately associated with the constructs. A total of seven constructs were developed and tested for the structural equation models

Structural equation modelling was conducted to generate parameter estimates and goodness of fit indices that will provide an adequate explanation of the nature and strength of the hypotheses and hypothesised relationships that were identified in Chapter Three. The structural equation models that were developed and estimated for Hypothesis 1, Hypothesis 2, Hypothesis 3, Hypothesis 4, Hypothesis 5, and Hypothesis 6 (H6a and H6b) had sufficient and satisfactory explanatory power for the nature and strength of the relationships enclosed in the hypotheses. It emerged from the structural equation modelling results that all the hypotheses were fully supported and reliably validated. Also, the results from the goodness of fit indices provide a satisfactory confirmation for the good fit of the structural equation models that were developed for the hypotheses.

CHAPTER SIX

DISCUSSION OF FINDINGS

6.1 Introduction

This chapter presents the interpretations for the integrated findings from the mean item score analysis, thematic analysis, and structural equation modelling.

6.2 BIM implementation strategies in South Africa.

6.2.1 BIM implementation strategies that are employed for driving BIM adoption on construction projects in South Africa.

The research sought to establish the BIM implementation strategies in use by asking the research participants to rate their level of agreement with the use of the identified BIM implementation strategies in the South Africa construction industry (objective 1). BIM implementation strategies are the policies and plans that are put in place for ensuring BIM adoption on construction projects. This research conceptualised these strategies to consist of top management commitment (BIM commitments), BIM motivations (these are strategies that describe the motivation required by the construction organisations towards the adoption of BIM tools, technologies, process, and platforms on construction projects), BIM capacity developments (these are strategies for developing the capacity of the employee to use BIM tools and technologies on construction projects), and BIM utilisation (policies and plans for strategic adoption of BIM on construction projects). The results show that the research participants agreed that 17 BIM motivations, ten BIM commitments, eight BIM capacity development, and nine BIM utilization strategies are in use in South Africa. The responses of the interviewees also confirm the use of these BIM implementation strategies for driving BIM adoption in South Africa. The possibility of getting high-value clients, the quest for competitiveness (the need to improve organisational performance and efficiency in the short and long term, the need to adapt to global best practices and trends prevalent BIM adoption among the top and successful firms), obligation to support development in the construction industry, and BIM success reports and publications were found to be motivating the adoption of BIM among construction organisations in South Africa. Other plans and policies that serve as motivation for BIM adoption in South Africa include the need for technological sophistication, BIM adoption as part of project team requirement, BIM adoption among peer firms, BIM adoption as part of clients' requirement, and the need to be socially acceptable to the clients.

Regarding the types of dedication put in place towards BIM adoption by the top management of construction organisations, it was found that the top management is dedicated to the coordination of the BIM process in the organisation, education of staff on the potentials of BIM, the introduction of collaborative teamwork culture in the organisation, development of new values, incorporation of BIM into the vision of the organisation, and ensuring effective use of BIM tools. It emerged that the top management are incorporating BIM into the vision of the organisation, allowing staff members to participate in the workflow redesign process, and ensuring effective use of BIM tools. Regarding the capacity development strategies, the results show that BIM workshops, BIM seminars, on-the-job BIM training for the employees, and corporate BIM training partnerships are the major strategies in use for BIM capacity development. The other major BIM capacity development strategies are self-initiated BIM training, BIM education in undergraduate programmes in the universities, BIM application and management programmes at a post-graduate level in the universities, and BIM technology educational programmes in colleges, technical and vocational institutes.

Concerning the BIM utilization strategies, the results reveal that construction organisations and professionals are developing BIM adoption plans that consider the appropriate form of collaboration required for projects, the appropriate import and export file format for projects, the appropriate intensity of collaboration required for projects, the appropriate BIM maturity levels for projects, the BIM platform for projects, the appropriate collaborative procurement systems for projects, and the appropriate level of development of building information models for projects. Similarly, building materials manufacturers are developing digital object identifiers for their products, and the assessment of BIM performance on projects is been undertaken.

There are many exciting findings in this research. First, the findings show that desire for technological sophistication, the quest for competitiveness, and the desire to be socially acceptable to the clients are motivating construction organisations and professionals to embrace BIM adoption. This means that construction organisations and professionals are concerned for, and conscious of, the quality of their profiles and performance. This makes them buy into BIM adoption as a way of acquiring and flaunting the latest technology in the construction industry. Competitiveness distinguishes a construction organisation or professionals from their rivals. It helps to guide against complacency, and helps to compete for clients and relevance in the construction industry. The quest for competitiveness through BIM adoption by construction organisations and professionals may be their strategy for eliminating complacency and establishing their superiority over the rival firms, or for fighting for relevance in their areas of specialisation.

The explanation for the use of social acceptability as a strategy for BIM adoption suggests that there is a natural desire in every organisation or professional to fit in with the trend in their work area, and to have a lasting and positive relationship with their clients. These social forces may be influencing the construction organisations and professionals to prevail over the barriers against BIM adoption. Second, the findings show that the top management of construction organisations are incorporating BIM adoption into the vision of their organisations, and have identified BIM competence as a new value for their staff members. Lack of BIM-induced changes in organisational culture is a major barrier to BIM adoption, because organisational culture determines the behaviour and values that characterise the work process and relationships in an organisation. It seems that the top management is strategising to overcome the BIM adoption barriers in their organisations by establishing BIM adoption as a current and future objective of their organisations. This explains why BIM competence had been identified as an added value for their staff members. Without BIM-competent staff members, it would be difficult to achieve the current and future BIM vision of these organisations.

The use of organisational vision and organisational values for organisational development is a common strategy of the top organisational management. It appears that the top management of construction organisations in South Africa are set to evoke this strategy for BIM adoption. Third, the findings reveal that the BIM capacity development strategies in use are self-initiated BIM training, on-the-job BIM training, and corporate BIM training partners. Self-initiated training is an adult learning method that allows people to learn with a unique dedication. It is also useful for the development of new knowledge and skills, and is helpful in achieving literacy with digital technologies. This indicates that construction professionals are banking on the advantage of self-initiated training in their quest to acquire BIM competence and skills. On-the-job BIM training as a BIM capacity development strategy would allow construction organisations to meet BIM specific needs. It is a hands-on method of teaching BIM skills, knowledge, and competencies, and its prevailing use among the construction organisations may be as a result of its suitability for organisational growth and development.

Corporate training partners provide industry-leading and relevant technical training through training consultants. This may be the reason why construction organisations favour it as a strategy for addressing their BIM needs and building BIM capacity. Fourth, the findings explain that a BIM adoption plan (BIM execution plan) and a BIM performance assessment are some of the major BIM utilization strategies in use by construction organisations. A BIM adoption plan or BIM execution plan is a strategy for making effective decisions on the use of BIM tools, technologies, principles, and processes. It provides a way of reaching the BIM goals of an organisation while achieving project expectations. A BIM adoption plan is useful in ensuring that resources are not wasted on BIM adoption, and it increases the chance of successful BIM adoption (Liu et al., 2017). The use of a BIM performance assessment as a BIM utilization strategy by construction organisations and professionals shows that they understand the importance of incorporating performance assessment into BIM adoption. It also shows that these organisations and professionals are keen on identifying areas for improvement in BIM utilization, getting positive feedback from BIM adoption, and assessing compliance with project expectations.

The study found that the construction organisations and professionals are determining the appropriate level of development for building information models for projects, attending BIM workshops and seminars, putting trust in higher education institutions for BIM education of future and current staff members, educating staff on BIM potentials, introducing collaborative teamwork culture in their organisations, adopting BIM as a way of supporting development in the construction industry, and hoping to get high-value clients by acquiring BIM competence. Logically, determining the appropriate level of development for building information models for the project is a useful BIM utilization strategy because it helps in specifying the content and reliability of building information models at various project stages. The usage of this strategy by the construction organisation and professionals implies that they are concerned about design details and specifications.

Similarly, collaborative teamwork culture is imperative to the reduction of BIM adoption barriers because BIM fosters cooperation and thrives in a collaborative team. Hence, every organisation with a determination for BIM adoption needs to introduce collaborative teamwork culture in their organisations. Construction organisations and professionals have an obligation to support development in the construction industry, because their continued survival depends on the well-being of the construction industry. It is a normal thing for construction organisations and professionals to seek to impress their clients. Therefore, using BIM competence to attract high-value clients is a strategy that is expected of any organisation or professional that is keen on attracting clients.

In this research, it emerged that the top management of construction organisations is coordinating BIM adoption processes in their organisations and exploring BIM on pilot projects, and that the building materials manufacturers are developing digital object identifiers for their products. This implies that the top management has a special interest in BIM, and that there is a general appreciation of the automatic quantity take-off that BIM provides. In the BIM process, automatic quantity take-off brings accurate and fast cost modeling, and it requires easy identification and determination of the process of building materials. The development of digital object identifiers for building materials supports the requirements of automatic quantification on the BIM process. The findings of this research are significant, in that they provide important insights into the plans and policies that are employed for reducing BIM adoption barriers. Although, it will be interesting to know the rate at which these strategies reduce BIM adoption barriers and increase the level of BIM adoption on construction projects. Nevertheless, the findings have provided information for policy-makers, construction industry, and organisation leaders, and all stakeholders in the construction industry on the appropriate plan's policies to be employed for driving BIM adoption.

The findings corroborate the conclusions by Akintola et al., (2017) and Kekana et al., (2015), which revealed that there is a level of BIM adoption among the construction organisations in South Africa (in particular, the multinational firms) because they want to be perceived as being technically matured or advanced. The conclusions of Akintola et al., (2017) and Kekana et al., (2015) also showed that there are no country-specific BIM guidelines and standards for BIM implementation in South Africa and that BIM adoption on construction projects in South Africa is driven by clients that are knowledgeable about BIM, private clients, and project management organisations that are consulting for clients. The mandatory use of BIM by the public client was found not to be in use as a BIM implementation strategy in South Africa in this current research. This is in contrast to earlier studies in China by Herr and Fischer (2019) and Zhou and Yang (2019), where the mandatory use of BIM by the public client was found to be the major motivation for BIM adoption.

6.2.2 BIM implementation strategies that will trigger a reduction in the barriers to BIM adoption.

There are certain BIM implementation strategies that are required but not currently employed for triggering a reduction in BIM adoption barriers. Therefore, the research participants were asked to indicate their level of agreement with BIM implementation strategies (categorised as BIM commitment, BIM motivation, BIM capacity development, and BIM utilisation strategies) that will be sufficient to trigger a reduction in the barriers against BIM adoption. As shown in the results, 31 strategies were perceived by the research participants as essential to getting the required quality of dedication and commitment from the top management of construction organisations. The results show that 30 BIM motivation strategies were agreed to by the research participants as necessary for triggering a reduction in the barriers against BIM adoption. The research participants agreed that 13 BIM capacity development strategies are essential to triggering a reduction in BIM adoption barriers. All 13 of the BIM utilisation strategies were perceived by the research participants as being essential to triggering a reduction in BIM adoption barriers. The findings from the thematic analysis also support the findings from the mean score analysis.

These findings represent a piece of up-to-date and important information on the BIM implementation strategies that are not in use, but that are essential to triggering a reduction in BIM adoption barriers. The findings imply that for a significant reduction in BIM adoption barriers, the top management of construction organisations must educate staff members on the potentials of BIM, provide in-house BIM training, adhere to BIM protocols, explore the usage of BIM on pilot projects, provide BIM technical support services in their organisations, and develop a BIM management processes. It becomes essential for the top management of construction organisations to incorporate BIM into their organisational vision, adapt BIM concepts to their organisational culture, ensure effective use of BIM tools, create a BIM-friendly organisational structure and culture, provide BIM infrastructures, and document BIM-based projects proceedings in order to reduce adoption barriers. The staff members must also be allowed to participate in the design of the work process redesign towards BIM adoption. This would allow the staff members to be comfortable with the changes in their work duties and activities. These changes must incorporate the introduction of new roles, new job titles, increment in staff development budget, and new appointments, such as BIM champions and BIM managers.

BIM adoption in an organisation and on construction projects requires investments, which signifies a financial risk. Hence, the top management of construction organisations must plan for BIM adoption risk management and development performance measures before BIM adoption. Additionally, the findings demonstrate that construction organisations and professionals will be motivated to adopt BIM tools, processes, and principles on construction projects when rival and peer firms adopt BIM and when there is prevalent BIM adoption among the top and successful firms. The availability of BIM proficient graduates, national BIM standards, guidelines on BIM protocols, the publication of BIM success stories, BIM adoption support funds, guidelines on BIM roles and responsibilities, and policies on copyright ownership of BIM will bring about a reduction in the barriers against BIM adoption.

Continuous organisational, personal, and professional development in terms of improved performance, improved efficiency, improved competitiveness, and technological sophistications may lead construction organisations and professionals to BIM adoption, which will translate to a reduction in BIM adoption barriers. BIM adoption may also be employed as a marketing strategy for organisational and professional services attracting high-value clients. As confirmed by the findings in this research, the needed BIM capacity development strategies include BIM education in secondary and higher education institutions, BIM workshops, and BIM training. Construction organisations may partner with BIM consultants for corporate BIM training, or adopt on-the-job BIM training for their employees. This effort is essential to triggering a reduction in BIM adoption barriers.

In the same vein, construction professionals could adopt self-initiated BIM training. Fresh graduates that are hopeful of high profile employment in successful construction organisations may embark on peer-group-influenced BIM training or pre-labor market-influenced BIM training. This step will add to their skill sets and boost their qualifications for the desired employment. If BIM adoption on construction projects is not well-structured and strategically planned, it will be difficult to encourage a widespread and sustained BIM adoption. As found in this research, BIM adoption on construction projects may be strategically planned by determining the appropriate import and export file format for different types of project complexities, determining the required BIM capacity of the construction project supply chain members based on the types of projects, and determining the appropriate number and types professionals to form the BIM supply chain.

The other strategies that are necessary for an effective and efficient BIM adoption on construction projects include the determination of the appropriate form of collaboration and intensity of collaboration required for different types of project complexities, and the determination of the appropriate collaborative procurement system for different types of project complexities. The appropriate BIM maturity must be matched up with the appropriate types of project complexities, and criteria for BIM performance assessment must be determined as a matter of necessity for a successful BIM adoption. Owing to the financial implications of BIM adoption on construction projects, it becomes imperative to determine the modality for sharing BIM costs and benefits between the client and the BIM supply chain members. This will allow the construction organisations and professionals to recoup their investments on BIM adoption and conveniently bear the financial burden of BIM adoption.

There are similarities between the essential BIM implementation strategies for driving BIM adoption found in this research and those described by Chan et al., (2019), Bakogiannis et al., (2020), Hatem et al., (2018), Dakhil et al., (2019), Dainty et al., (2017), Kahkonen and Keinanen (2016), Zhou and Yang (2019), Elagiry et al., (2019), Lindblad and Guerrero (2020), Mustaffa et al., (2017), Siriwardhana et al., (2018), Ding et al., (2015), Son et al., (2015), and Cao et al., (2017). These previous studies indicated that BIM commitments, BIM capacity development, and BIM motivations – such as the mandatory use of BIM by the public client, BIM education, BIM pilot projects, development of BIM guidelines and standards, provision of leadership and creation of a supportive environment, financial provisions for small firms, organisational rivalry and competition, and BIM literacy – will greatly impact the level of BIM adoption on construction projects. These findings have important implications for developing countries where BIM implementation is not existent or at an early stage. The findings of this research provide information on the formation of plans and policies for accomplishing BIM implementation in the construction industry. The findings of this research have implications for setting BIM goals, developing BIM implementation framework, allocating resources for BIM implementation, and defining the key performance indicators for BIM implementation. This research has made it clear that it will be wrong to underestimate the requirements of BIM implementation.

6.3 Indicators of a reduction in barriers to BIM adoption in South Africa.

6.3.1 The barriers against preliminary BIM adoption on construction projects in South Africa.

To achieve the second objective of this research, this research investigated the barriers against preliminary BIM adoption on construction projects in the South African construction industry by asking the research participants to rate the occurrence of the identified 22 barriers against preliminary BIM adoption on construction projects they had participated in. These barriers are collectively referred to as the obstacles preventing the efforts by construction organisations, construction professionals, and construction subcontractors to explore the use of BIM on construction projects. From the results, it is apparent that all the 22 barriers have *a somewhat high occurrence* and *high occurrence* on the projects where the research participants were involved. The findings show that the mean item score for all the barriers ranges from 3.21 to 3.55, thereby indicating a *somewhat high occurrence* and a *high occurrence*. The absence of in-house BIM competent professionals, lack of resources to train employees, unavailability of BIM competent professionals in the labour market, and lack of cooperation among firms in the industry were found to have a *high level of occurrence*. Other barriers with a *high level of occurrence* are: lack of understanding of BIM, non-communication of BIM concept by relevant industry leadership, lack of cooperation among professionals in the industry, lack of BIM awareness among clients, lack of enforcement from industry leadership, lack of a business case for BIM adoption, lack of resources to acquire BIM tools and technologies, and lack of enforcement from government agencies.

The barriers that were found to have *somewhat high occurrence* comprised of a lack of interest in BIM among clients, lack of clarity of professional roles in BIM, satisfaction with existing work methods and process, lack of trust among firms in the industry, unavailability of BIM guidelines and standards, clashes in professional responsibility in BIM, incompatibility and interoperability of BIM software technologies, lack of trust among professionals in the industry, and lack of policies and regulations on copyright ownership.

This finding reveals a discovery on barriers against BIM adoption, in that lack of understanding of BIM and non-communication of BIM concepts by relevant industry leadership have not been previously emphasised as a major barrier to BIM adoption. Previously, lack of BIM awareness, lack of demand for BIM, and unavailability of BIM standards have been the traditional and commonly identified BIM adoption barriers (Liu et al., 2015; Arunkumar et al., 2018). This new finding means that it is not enough to create BIM awareness in the construction industry. Rather, the industry leaders need to ensure that the construction workers, professionals, and clients understand the concept of BIM. As expected, the findings were in line with the prevailing conclusion that the absence of in-house BIM competent professionals, lack of BIM infrastructure to train employees, and unavailability of BIM competent professionals in the labour market are partly responsible for slow adoption to BIM on construction projects.

This confirms the existence of insufficient BIM skills and capability. It also implies that construction organisations and educational institutes are not fully prepared to create BIM capability. The lack of trust among construction professionals was not indicated to be a major barrier to BIM adoption. This is surprising because BIM was conceived as a result of the need to resolve fragmentation and lack of trust among construction professionals. Therefore if a lack of trust among construction professionals did not constitute major barriers against BIM adoption, this implies that a form of trust-based relationship exists among the construction professionals as a result of the procurement systems in use for construction projects. Also, it could be that the construction professionals were not aware of the threats that a lack of trust among them poses to BIM adoption.

It was interesting to find that clashes in professional responsibility and roles in BIM processes are not constituting a major obstacle to BIM adoption on construction projects. Since there are no clear cut BIM roles and responsibilities yet, clashes in BIM roles and responsibilities would have been major obstacles to the smooth flow of BIM adoption. For clashes in professional responsibility and roles in BIM processes not to have had a high occurrence as an obstacle to BIM adoption, it means that the project participants were enthusiastic about BIM adoption and exhibited cooperative tendencies which allowed teamwork and shared responsibilities. The lack of enforcement from the government was also found to have high occurrence as a barrier to BIM adoption. This implies that there are no government policies and legislation on BIM adoption which would have compelled the construction organisation and construction professionals to prioritize BIM adoption on construction projects. This implies that company policies and the quest for a competitive edge by construction companies are driving BIM adoption on construction projects.

These findings enhance the understanding of BIM adoption barriers by showing that the efforts to explore the use of BIM on construction projects will not yield a successful BIM adoption unless the construction organisations, professionals, and sub-contractors are BIM competent and have an understanding of BIM concepts. These findings have important implications for the theory and practice of BIM adoption. First, it establishes that there are significant barriers that affect the decision to explore the use of BIM on construction projects. Construction organisations that are considering the exploration of BIM adoptions should take note of these barriers in order to ensure a smooth preliminary BIM adoption. Second, it implies that the government and industry leaders are not aggressively pursuing solutions to the challenges in the construction industry such as BIM adoption. Lastly, it provides a list of requirements for BIM adoption practitioners or BIM managers. Though this research has reported novel barriers against BIM adoption, earlier related studies such as Yasser et al. (2019), Jamal et al., (2019), Kekana et al., (2015), Georgiadon (2019), Al-Yami and Sanni-Anibire (2019), Oestereich and Teuteberg (2019), Elagiry et al., (2019), Nnaji and Karakhan (2020), Olawuni and Chan (2020), and Zhang et al., (2016) provide support for these findings.

Yasser et al. (2019) concluded that the conceptualization of BIM as an innovation in transition has created a poor knowledge about BIM which is responsible for low BIM implementation. In South Africa, Kekana et al., (2015) identified a lack of BIM education, unavailability of BIM competent professionals, lack of BIM expertise, lack of BIM skills and training as the major barriers of BIM implementation. While Georgiadon (2019) indicated that limited in-house BIM experts are the major barrier to initial BIM adoption. The lack of BIM execution guidelines and BIM specialists was indicated to be the most significant challenge in China by Zhang et al., (2016). The investigation of the barriers against preliminary BIM adoption on construction projects as undertaken in this research was limited to the South African construction industry; hence, the generalizability of the findings of this research is subject to the status and sophistication of BIM implementation in the construction industry.

6.3.2 The barriers against sustained BIM adoption on construction projects in South Africa.

The research investigated the barriers against sustained BIM adoption on construction projects in South Africa by asking the research participants to rate the occurrence of the 28 identified barriers against sustained BIM adoption on construction projects they had participated in. The barriers against sustained BIM adoption refer to the obstacles preventing the continuous use of BIM at various stages of construction projects and usage of BIM on subsequent construction projects. It emerged from the results that five barriers have *high occurrence* as obstacles to BIM adoption on construction projects. These are: lack of information on BIM tools and technologies, top management not engaging BIM consultants to facilitate BIM usage, lack of understanding and identification of BIM tools and technologies, failure to understand how BIM adoption will change business, and lack of coordination across different supply chain members. Twenty-three (23) barriers were found to have a *somewhat high occurrence* as obstacles to sustained BIM adoption on construction projects. These are: unavailability of BIM infrastructures in the organisation, the rigidity of organisational structures, lack of capacity to meet BIM implementation demands, unavailability of BIM implementation experts, lack of collaborative teamwork culture in the organisation, and lack of a clear strategy for BIM use on projects.

Lack of framework for BIM platforms selection, lack of coordination across different functional areas, lack of patience and understanding of the structural changes needed, skepticism about benefits of BIM adoption, employees' unwillingness to accept changes, the perspective of BIM as just an item of technology, and lack of awareness of the competitive situation of the firms were also found to have a *somewhat high occurrence* as obstacles to sustained BIM adoption on construction projects. Other barriers include lack of patience and understanding of the cultural changes needed, the inadequacy of BIM to support the existing organisation work, the inadequacy of BIM to support the existing business process, the inadequacy of BIM to meet project expectations, conflict of interests between BIM adoption and organisational vision and objectives, fear of loss of competitive advantage, lack of motivation for workers, inappropriate change management processes, the inadequacy of BIM to meet organisational expectations, and the inadequacy of BIM to meet clients' expectations.

The findings show that the continuous use of BIM at various stages of construction projects and the use of BIM on subsequent projects mainly depend on the availability of information on BIM tools and technologies, understanding of BIM tools and technologies, understanding of BIM adoption-induced changes in business process, the designation of BIM champion position in construction organisations, and involvement of BIM consultants. It seems that BIM consultants are required to provide the latest information and training on BIM tools and technologies, while the BIM champion is required to disseminate the latest information on BIM tools and technologies in their organisation, as well as ensure the application of the existing and new BIM tools and technologies at various stages of construction projects and on subsequent projects.

It was surprising to find out that BIM was considered inadequate to support the existing organisational work, business process, and the meeting of project expectations. This could be a result of a lack of information and understanding of the benefits of BIM by the construction organisation and professionals. It also reinforces the need to align the benefits of BIM adoption with project expectations, because the awareness of the strong link between the BIM adoption benefits and the project expectations that constitute project success will enable the use of BIM at various stages of construction projects and on subsequent projects. BIM process cannot disrupt business and work processes because the cooperation, integration, and collaboration that the BIM process provides improve the existing work and business processes. There are so many findings in these results that are contrary to the expected outcomes. First, the unavailability of BIM implementation experts was found, to a certain degree, to function as a barrier to sustained BIM adoption on construction projects. BIM implementation is a revolutionary process in the construction industry that had attracted attention and interest globally. It is surprising to find that there is a dearth of experts on BIM implementation. This could be as a result of the lack of in-depth understanding of BIM implementation. It could also mean that research works on BIM adoption had not focused more on BIM implementation strategies.

Second, lack of patience and understanding of the structural and cultural changes needed is, to some extent, preventing a sustained BIM adoption on construction projects. The surprise in this finding is that it suggests that construction organisations are culturally and structurally flexible. This flexibility may support and ensure a smooth transition from the existing work process and ethics to the BIM process and principles, but it also exposes the construction organisations as lacking a well-defined and enshrined organisational culture and structure. Although, the structural and cultural flexibility of construction organisations could be a result of the dynamics of and uncertainties in the construction industry, which force the construction organisations to move with the events and developments in the construction industry so as to survive and remain competitive. BIM implementation is one of the latest developments in the construction industry that justifies the cultural and structural flexibility of construction organisations.

Finally, the perspective of BIM as just an item of technology moderately affects sustained BIM adoption on construction projects. This finding was surprising, because BIM adoption brings relational, procedural, and technological revolution. Therefore, a BIM adoption with an emphasis on the technological revolution will surely frustrate sustained BIM adoption on construction projects. This is because the main benefits of BIM adoption, and what differentiates BIM from the computer-Aided-Design, are the relational and procedural parts of BIM. The technological revolution in the construction industry as led by BIM adoption brings increased use of technologies for design, construction, and management processes. However, without the adoption of the BIM processes and principles together with BIM technologies, the challenges of the construction industry, typified by poor project delivery, will persist.

The explanation for the popular belief that BIM is just an item of technology and that non-adoption of BIM processes and principles will not negatively affect sustained BIM adoption is that construction organisations and professionals simply lack the understanding of BIM concepts. These findings provide important insight into the negative impacts that non-availability of information on BIM tools and technologies, non-consultation with BIM experts, and non-availability of BIM champions in organisations have on BIM adoption at various stages of construction projects and the use of BIM for subsequent construction projects. There are many factors that could cause construction organisations and professionals to discontinue the use of BIM on a construction project after the design stage and after the pilot project for BIM adoption. These factors have been ignored, owing to the assumption that the exploration of BIM tools and technologies on a pilot project or at the design stage of a project will guarantee the continuous use of BIM, or suffice for BIM adoption.

It is not certain that the benefits of BIM will be realised on the first BIM-based projects or by adopting BIM only at the design stage. However, the decision to continue with BIM adoption at other stages of a project, and on a subsequent project, must hinge on a certain factor. The findings of this research have confirmed the existence of such factors. Previous research into BIM adoption barriers had indicated that lack of understanding of the usefulness of BIM processes at project phases, lack of BIM capabilities, difficult BIM learning curve, scarcity of BIM managers and specialists, and lack of BIM experience are major barriers against BIM adoption on construction projects (Boton et al., 2020; Chen and Ni, 2019; Ma et al., 2019; Jamal et al., 2019; Enshassi et al., 2019; Herr and Fischer, 2019). These studies provide support for the findings of this research. Nevertheless, the findings of this study must be interpreted cautiously, because the barriers against sustained BIM adoption on construction projects may differ from country to country.

6.3.3 Indicators of a reduction in barriers against preliminary and sustained BIM adoption on construction projects in South Africa.

The indicators of a reduction in barriers against preliminary and sustained BIM adoption on construction projects were investigated in this research by asking the research participants to rate their level of agreement with the occurrence of the identified indicators of a reduction in barriers against BIM adoption. A total of 32 indicators were identified and presented to the research participants for their ratings on a five-point Likert scale. The results revealed that the research participants agreed to six indicators. These indicators have a mean item score that is above the 3.41 cut-off point for a 4-point on the Likert scale. These indicators are employees' readiness to accept changes, acquisition of resources for BIM training of the employee, acquisition of BIM software technologies, BIM-induced changes in construction business process, availability of BIM infrastructures in the organisations, and availability of policies and regulations on copyright ownership. The employees' readiness to accept changes indicates that employees have realised that the BIM revolution has come to stay and are prepared not to lose their jobs as a result. Also, it indicates that the employees have realised that the work process will change as a result of the BIM revolution, and that new roles and responsibilities are emerging; therefore, they are ready to learn BIM skills. The readiness of employees to learn BIM skills complements the acquisition of BIM training resources in construction organisations because they are indispensable tools to enhance training and education and to deliver professionals skills and new work process skills.

BIM software technologies are essential parts of BIM training resources. The acquisition of BIM software technologies in the construction organisations is geared towards training the employees on software technologies that were developed and designed specifically for the BIM process. The occurrence of BIM-induced changes in the construction business process as an indicator of a reduction in BIM adoption barriers means that a set of BIM-related activities and tasks that employees must carry out in a specific order are targeted at achieving the BIM goals of the organisations. Likewise, the availability of policies on copyright ownership indicates that BIM authors (or building information models developers) can protect their intellectual properties. This will in no doubt help prevail over the copyright ownership aspect of BIM adoption barriers. The acquisition of BIM software technologies by the construction organisations is an expected gesture from the construction organisations towards reducing BIM adoption barriers.

However, the readiness of the construction organisation employees to adopt BIM was not expected, owing to their renowned resistance and reluctance to change. It appears that both the organisations and their employees (construction professionals) have come to the realisation that change is constant. It was found that the application of BIM tools to projects and the acceptance of BIM competency as a competitive advantage were not viewed as major indicators of a reduction in the barriers against BIM adoption. It appears that there is a general understanding that BIM stands for more than the application of BIM software tools to projects, or that construction professionals still believe that BIM is a mysterious innovation that is still evolving.

Regardless of these findings, the use of BIM tools remains an essential part of BIM adoption, and it would have been expected that the application of BIM tools to projects be perceived as a major indicator of a reduction in barriers against BIM adoption. Or, it may be that the application of BIM tools to projects was not perceived as widespread and intensive enough for it to indicate a notable reduction in BIM adoption barriers. The findings also suggest that some organisations and professionals are still in denial of the competitive advantage that BIM competency bestows in BIM competent organisations and professionals. It seems that these organisations and professionals who are in denial of the competitive advantage that may be derived from BIM competencies believe that BIM is just the latest technology fad that will soon blow over just like the other old and forgotten innovations in the construction industry.

It also emerged that regular organisation of BIM workshops by industry leadership, and availability of interoperable BIM software technologies were not perceived to be major indicators of a reduction in barriers against BIM adoption. This is contrary to expectations, because BIM workshops serve as an effective promotion for BIM awareness. Attending BIM workshops creates learning opportunities and allows BIM application methods and ideas to be passed on to the participants. Therefore, it was surprising to find that the regular organisation of BIM workshops was not seen as a major indicator of a reduction in BIM adoption barriers even though it is useful in reducing BIM unawareness and non-understanding of BIM concepts. The BIM process depends on the integration of project information and the integration of project participants; therefore, the BIM process will not be possible and BIM adoption will become meaningless without the availability of interoperable BIM software technologies.

Thus, it was contrary to expectations that the availability of interoperable BIM software technologies was not perceived to be a major indicator of a reduction in barriers against BIM adoption. Among the indicators of a reduction in barriers against BIM adoption that are found in the South African construction industry are the understanding of responsibilities in BIM adoption by the BIM supply chain, availability of BIM competent professionals in the labour market, and aligning organisational vision and culture with BIM adoption requirements. This shows that both the construction organisations and professionals are making efforts towards the elimination of BIM adoption barriers in the South African construction industry. The findings of this research imply that BIM adoption and implementation are still at the early stages in the South Africa construction industry, as fewer indicators of a reduction in BIM adoption barriers were noticeable. Majorly, the construction organisations and professionals were acquiring BIM resources and setting up BIM infrastructures.

6.4 Level of BIM adoption on construction projects in South Africa

This research investigated the level of BIM adoption on construction projects in South Africa by asking the research participants to identify BIM-based projects on which they are most conversant with (objective 3). The research participants were requested to answer questions relating to the criteria for assessing BIM performance, BIM capacity (BIM skills and competencies), BIM tools employed, types of building information models developed, and level of clarity of objects that were used to develop building information models for the identified BIM-based projects. From the results, it can be seen that six BIM performance assessment criteria were used to a moderate extent. These are: improved work quality, improved client satisfaction, fast project delivery, effective communication, broadening of the understanding of project needs, and increased knowledge transfer. The result shows that construction plans and time schedules, as well as construction health and safety information models, were the only building information models that were developed to a moderate extent for BIM-based construction projects. The results revealed that BIM capacity (competence in 3D-CAD tools and software technologies, information integration skills, multi-disciplinary collaboration skills, competence in BIM tools and software technologies, and information exchange skills) for the BIM-based construction projects were required and utilised at the functional level.

The result shows that 17 BIM tools (budget simulation, construction sequencing, visualisation, life-cycle costing, clash detections, and model checking, construction simulation, As-built BIM model, virtual mock-up models, walkthroughs, automatic cost data extraction, automatic quantification, optimization, 3D-object based models, digital fabrication, automatic cost data update, lifecycle analysis, and BIM maintenance plans and technical support) were employed on the BIM-based construction projects to some extent. It was found that all the levels of objects' clarity (G0 – schematic, G1 – concept, G2 – defined, and G3 – rendered) were used to some extent to develop building information models for BIM-based construction projects.

This finding suggests an elementary and a disorganised BIM adoption on construction projects in South Africa. This influence is based on the fact that there is no intensive use of BIM tools, and that the required BIM capacity of the project participants was not at the expert level, specialist level or experienced level. Also, the findings indicate that BIM performance assessment is not intensive, fewer building information models were developed for projects, and emphasis was not placed on the levels of objects' clarity of building information models. The BIM-based construction projects in which the research participants were involved were not assessed for improved cooperation, the occurrence of trust and commitment, improved information quality, improved client participants, waste elimination, fewer requests for information, reduced contractual claims, and fewer change order. These are common and basic benefits of BIM adoption on construction projects; hence it is surprising to find that BIM-based construction projects were not assessed for these benefits. The only explanation for this may be that the project participants thought that, since the BIM capacity employed for these projects was not at the higher level (expert, specialist, and experienced level), it would be inappropriate to evaluate the BIM-based projects for every BIM adoption benefit. However, it would have been expected that the appropriate BIM performance assessment would have been the evaluation of the BIM-based projects for common and basic BIM adoption benefits as a result of the use of BIM capacity at the functional level. Doing this would have provided the project participants with feedback on how to improve their BIM capacity and the level of BIM adoption.

It also emerged that the common BIM tools such as visualisation, construction sequencing, clash detections and model checking, automatic cost data extraction, automatic quantification, conceptual and detailed energy analysis, 4D scheduling, and animations were sparsely used on the BIM-based construction projects executed by the research participants. This suggests insufficient BIM skills and competencies on the part of the project participants. The use of BIM capacity at the functional level provides support for this explanation. Equally, the general types of building information models (cost and quantities information model, structural information model, architectural information model, mechanical services information model, and lighting analysis information model) were not developed for some of the BIM-based projects reported. This means that BIM adoption plans for these BIM-based projects were not well executed or managed by the responsible parties on these projects. Therefore, most of the organisations and professionals who partook in the BIM-based projects were not mandated to develop and share their discipline-specific building information models. It can be inferred that project databases were created for these BIM-based projects, as the creation of a project database would have required the development of a set of discipline-specific building information models, particularly the common types of building information models.

These findings show a lack of emphasis on the creation of project databases for the BIM-based projects, because the creation of the integrated and interactive database was not among the predominant criteria for assessing BIM performance on the BIM-based projects. The issues that emerge from these findings are useful and important to the stakeholders in the South African construction industry, and, by extension, those in developing countries. The findings indicate a disorganised and poorly managed BIM adoption plan for BIM-based construction projects. This signifies that beyond the emphasis on the development of BIM competences, more emphasis must be laid on the development of BIM management skills. It emerged that the level and success of BIM adoption construction projects depend largely on the success of BIM management. Likewise, the findings imply that the concept of BIM adoption must be differentiated from the concept of BIM and BIM implementation. BIM adoption becomes meaningful and practical when BIM tools, principles, and processes are applied to construction projects in a strategic manner. As found in this research, the manner of BIM application on construction projects suggests that construction organisations and professionals did not fully understand the concept of BIM adoption.

Previous studies that have investigated BIM adoption models globally corroborate the findings in this research. In terms of the extent of BIM adoption, Zhang et al., (2016) reported that the level of BIM adoption on construction projects in China is relatively immature. Froise and Shakantu (2014) concluded that the level of BIM adoption on construction projects in South Africa is immature; while Kekana et al., (2015) reported that about 38% of construction organisations in South Africa are using BIM on their projects. Herr and Fischer (2019) concluded that BIM adoption is generally at the low skill level and basic technological level, and that most buildings in the developing countries are non-complex and can be delivered without a high degree of BIM adoption. The study by Yasser et al., (2019) reported that BIM is not always adopted for all projects by construction organisations that had adopted BIM. Regarding the BIM software technologies in use, the conclusions by Herr and Fischer (2019) indicated that BIM adoption on construction projects has been software-centric.

Similarly, Yasser et al., (2019) concluded that construction organisations have adopted BIM technologies more than BIM processes. The findings of Zhang et al., (2016) and Olatunji (2011) also indicated that Autodesk Revit, Vico, Naviswork, and ArchiCAD are the most popular BIM software technologies in Australia and China. Concerning the BIM tools usage, Cao et al., (2015), Zhang et al., (2016), and Latiffi et al., (2016) concluded that clash detection, optimisation, quantity take-off, 4D simulation, and visualisation are the most adopted BIM tools in Malaysia and China. With regard to the BIM performance assessment criteria, Herr and Fischer (2019) concluded that the main criteria for assessing BIM performance in China are improved time and cost performance. Kong et al., (2020) concluded that BIM adoption helps with faster and easier decision-making, improves collaboration, and coordination between disciples in Malaysia.

6.5 Level of Integration and Collaboration among the BIM Supply Chain Members in South Africa.

This research investigated the levels of integration and collaboration among the construction organisations and professionals (BIM supply chain members) who partook in the BIM-based construction projects (objective 4). The main outcome of BIM adoption on construction projects is the occurrence of integration and collaboration among the BIM supply chain members. Therefore, the research participants were asked to rate the extent to which trust-based relationships, information sharing and exchange, knowledge sharing and transfer, and communication network occurred among the BIM supply chain members on the identified BIM-based projects.

The result reveals that there are 15 features of trust-based relationships that occurred among the BIM supply chain members to a moderate extent. These are: problem-solving ability, the competence of personnel, competence of organisation, consistent integrity, and openness in sharing information, mutual exchange of ideas, honesty and mutual commitment, freedom to state opinions and perspectives, and cross-functional cooperation. Others include: the display of confidence for each other by supply chain members, support for innovation and learning, shared interests and project expectations, conflict resolution, interpersonal relationship, and inter-organisational relationships. The result reveals nine features of information sharing and exchange that occurred among the BIM supply chain members to a moderate extent. These are: the credibility of information, clarity of information, the high quality of information, accuracy of information shared, usage of collaborative electronic media for information sharing, timely sharing of information, adequacy of information, enhanced interpersonal sharing and exchange of information, and selection of information sharing channels.

As shown in the results, there are 17 features of network communication that occurred to a moderate extent among the BIM supply chain members. These features include documentation of communication, the formation of open and formal communication channels, communication across the stages in the project life-cycle, regular interpersonal communication, adoption of common electronic communication platforms, the establishment of a secured line of communication, and usage of communication protocols. Others are: regular team communication, real-time communication, feedback communication, regular inter-group communication, timely communication, the flexibility of formalities, regular inter-organisational communication, positive corporate communication, the multi-directional flow of information, and adoption of joint problem-solving techniques.

As revealed in the result, there are 18 features of knowledge sharing and transfer that occurred to a moderate extent among the BIM supply chain members. These features include valued decision-making, understanding of information, quick decision-making, the high quality of information, collective decision-making, willingness to share resources, inter-personal knowledge sharing, inter-team knowledge sharing, and usage of collaborative electronic media for knowledge sharing. Others are: the identification of clashes and omissions in the information models, review of projects after completion, sharing of knowledge on best practices among the supply chain members, inter-personal knowledge sharing, database creation and management, inter-group knowledge sharing, knowledge documentation in form of the project proceeding, sharing of collaborative experiences among the BIM supply chain members, and extraction of measurement information from the information models.

The themes from the analysis of the responses of the interviewees also correspond with the features of integration and collaboration that occurred to a moderate extent among the BIM supply chain members. It can be inferred from these findings that BIM adoption on construction projects enabled the project participants to trust one another's problem-solving ability, competence, opinion, and perspectives. It appears that the project participants acted and related to one another with integrity and honesty as a result of the BIM process requirements. It could also be inferred that there was openness in the sharing of information, cooperation, and mutual exchange of ideas on the BIM-based construction projects. This suggests, to a reasonable extent, that there is a level of trust between the project participants.

Apparently, BIM adoption on construction projects enabled the project information developed by the project participants to be of high quality, as revealed by the adequacy, credibility, clarity, accuracy, and timeliness of the information that was shared among the project participants. The findings suggest that the project managers or BIM managers selected a dedicated channel for information sharing for the BIM-based construction projects. This fosters collaboration and integration of both the project information and project participants, because the use of a dedicated information sharing channel enables the sharing of both general and sensitive information. Also, it signifies intense interactions among the project participants. The evidence in the findings suggests that BIM adoption has created a network of communication that spans through interpersonal, inter-group, and inter-organisational networks. This suggests a new type of communication that has a multi-dimensional flow of information, requires the formation of open and formal communication channels, span across all the stages in the project life cycles, requires the use of electronic communication platforms, requires the use of communication protocols, and occurs in real-time. The knowledge sharing and transfer occurred as a result of BIM adoption on construction projects among the project participants across inter-team, interpersonal, inter-group, and inter-professional networks. Also, it describes a type of BIM knowledge that is required for the identification of clashes and omissions in building information models, as well as for a valued, quick, and collective decision making. This may be the type of knowledge that comes from BIM experience, BIM standards, and BIM training. The findings further suggest that there was documentation of BIM knowledge in the form of resources, project databases, and project proceedings.

Even BIM adoption on construction projects is itself a risk (Liu et al., 2017); therefore, it is surprising to find risk sharing not occurring as a moderate communication feature among the project participants. Risk sharing is an element of collaboration, and it is required to reduce the likelihood and impact of risks. Its low occurrence among the BIM supply chain members may be due to their unawareness of the risks of BIM adoption on construction projects. Also, there is a low occurrence of the absence of competing interests and professional stereotypes among the project participants on the BIM-based projects. The effect of this is that the project interests might not take necessary precedence, and the project participants might not have a focused and clear mind-set towards the pursuance of common interest.

A major cause of fragmentation is professional stereotypes, because it leads to interpersonal rivalry and encourages a 'silo mentality' among project participants. Hence, it is surprising to find that the project participants still manage to exhibit some measure of inter-professional rivalry in BIM-based construction projects. Another surprising finding is the relatively low occurrence of non-adversarial relationships and the limited use of both file-based and server-based data interoperability. This suggests the occurrence of certain non-collaborative activities and unsupportive behaviours among the project participants. The limited use of both file-based and server-based data interoperability could only suggest that the BIM workflows for the BIM-based projects were not smooth and effective. It's almost certain that some of the building information models that were developed for the BIM-based projects would have errors, ambiguities, and omissions. In the same way, the findings indicate that some of the structured e-meetings that took place on the identified BIM-based projects were not agenda-driven, open-ended, and problem-solving.

Present was also the reciprocal flow of information, data federation, and the creation of a single project database that occurred to a limited degree among the BIM supply chain members. This depicts a low occurrence of two-way interaction and cooperation among the project participants. It also indicates the poor management and storage of project information, and confirms that not all the project participants had free and easy access to the project information from different sources. The findings of this research have provided some evidence in support of the postulations on the occurrence of collaboration and integrations among the BIM supply chain members. The findings have provided new insights and concepts for the features of BIM-enabled integration and collaboration. The findings in this research are consistent with those of studies by Ibrahim and Belayutham (2019), Matthews et al., (2018), Alreshidi et al., (2018), and Liu et al., (2017). The findings by Ibrahim and Belayutham (2019) indicated that integration and collaboration, such as deep understanding of project needs, mutual interests, and knowledge sharing, occur among the BIM-SCM. The conclusions by Matthews et al., (2018) indicated that BIM-SCM must be transparent and exhibit the ability to share information, and must have easy access to information. Alreshidi et al., (2018) concluded that full integration and collaboration is yet to be realised despite active BIM adoption; while Liu et al., (2017) concluded that sharing of decision-making, open communication, problem-solving, and trusting behaviours are essentials to integration and collaboration among the BIM-SCM.

6.6 Modelling the interactions between the BIM implementation stages in South Africa.

6.6.1 The relationship between BIM implementation strategies and the level of BIM adoption on construction projects.

The interactions between the BIM implementation stages as theorised in the five hypotheses were tested to achieve the fifth objective of this research. Hypothesis 1 theorised that there is a positive relationship between BIM implementation strategies and the level of BIM adoption on construction projects that were tested using structural equation modelling. The parameter estimates of the structural equation model show evidence that fully validated the hypothesis and its direction. There were 19 hypothesised relationships in the model, and all were found to be statistically significant. The findings support the hypothesis. The BIM implementation strategies in use were found to have a positive association with the level of BIM adoption on construction projects. This suggests that the use of BIM implementation strategies give rise to BIM adoption on construction projects. The explanation for this is that the plans and policies that were put in place by the stakeholders in the South Africa construction industry are yielding efforts that bring about BIM adoption on construction projects.

Among the BIM implementation strategies in use, BIM utilisation strategies were found to have the strongest association with the level of BIM adoption on construction projects. This was closely followed by BIM motivation strategies. BIM commitment (top management commitment strategies) and BIM capacity development strategies were found to have a moderate association with the level of BIM adoption on construction projects. The explanation for this is that BIM utilisation strategies and BIM motivation strategies were the most popular or the most effective BIM implementation strategies. It suggests that BIM capacity development strategies and BIM commitment strategies were unknown to the stakeholders, or were not as effective in driving BIM adoption on construction projects. Inappropriate application or execution of these strategies could also account for their moderate association with the level of BIM adoption on construction projects.

Regarding the sub-constructs for the level of BIM adoption on construction projects, the findings show that the types of BIM tools and the level of clarity of objects that were used to develop building information models for the BIM-based construction projects have a strong association with the BIM implementation strategies in use. BIM performance assessment criteria, BIM capacity utilized on the BIM-based construction projects, and types of building information models developed for the BIM-based projects have a moderate association with the BIM implementation strategies. These findings suggest that the BIM utilisation strategies in use focused more on the use of BIM tools and the level of details of building information models. This explains the moderate correction in the other aspect of BIM adoption.

The findings also indicate a scarcity of BIM skills and competencies in the South African construction industry, and a lack of awareness of the strategic importance of BIM performance assessment. Capacity development is a valuable strategy in that it has many long-term benefits, such as improvement in the expertise, competence, and skills of the employee. Therefore, it is surprising to find that the use of BIM capacity development strategies was not common among construction organisations. The model can be used to understand how to develop an attractive BIM implementation plan and strategically allocate organisational resources for BIM implementation. It is also useful in promoting BIM adoption and identifying plans and policies that are useful and imperative to a widespread and successful BIM adoption. The nature and strength of the interaction between BIM implementation strategies and BIM adoption as found in this research are broadly consistent with earlier studies by Dowsett and Harty (2019), Cao et al., (2017), Shirowzhan et al., (2020), and Yang and Chou (2018). However, there is a need to extend the understanding of the relationship between BIM implementation strategies and the level of BIM adoption on construction projects by considering additional variables for the level of BIM adoption on construction projects. The additional variables that could be considered in future research include the level of development of the building information models, collaborative procurement process, team composition for BIM supply chain, BIM software technologies adopted, and BIM principles.

6.6.2 The relationship between BIM implementation strategies and barriers to BIM adoption.

This research tested the hypothesis (Hypothesis 2) that proposed that there is an inverse relationship between BIM implementation strategies and barriers against preliminary and sustained BIM adoption on construction projects. All four hypothesised relationships in the structural equation model have acceptable validity and significance. The path analysis for the model of the relationship between BIM implementation strategies and barriers against preliminary and sustained BIM adoption on construction projects shows a weakly negative but significant association between the two constructs. This confirms the existence of an inverse relationship between the two constructs, which is an indication that as the use of BIM implementation strategies increases, the barriers against BIM adoption decrease. These findings suggest that the use of four categories (BIM motivation, BIM commitment, BIM capacity development, and BIM utilisation strategies) of BIM implementation strategies are effective in bringing about a reduction in the BIM adoption barrier. However, the relationship is weak, which indicates that the use of the BIM implementation strategies may be in the early stage. The weak relationship between these two constructs also indicates an improper use or ineffectiveness of the BIM implementation strategies.

A specific investigation is required to ascertain the explanation for the weak negative relationship between the BIM implementation strategies and barriers against preliminary and sustained BIM adoption on construction projects. Until further studies are conducted, the best explanation for the weak relationship is that the use of BIM implementation strategies is in the early stage in South Africa and their impact on the BIM adoption barrier has not reached an advanced level. The findings did not show any significant difference between the strength of the association between BIM implementation strategies and barriers against preliminary BIM adoption, and the strength of association between barriers against sustained BIM adoption, and BIM implementation strategies. Although, as shown in the path analysis diagram (Figure 9.2), the association between BIM implementation strategies and barriers against sustained BIM adoption is stronger than that between BIM implementation strategies and barriers against preliminary BIM adoption. However, both associations are still weak. The differences in the strength of associations suggest that the effect of BIM implementation strategies on the barriers against sustained BIM adoption is more pronounced than their effects on the barriers against preliminary BIM adoption. There is no enough evidence to ascertain this assertion.

The structural equation model revealed a moderate association between BIM commitment strategies, BIM capacity development strategies, and the barriers against preliminary and sustained BIM adoption on construction projects. The findings also showed a strong association between BIM motivation strategies, BIM utilisation strategies, and the barriers against preliminary and sustained BIM adoption on construction projects. BIM adoption barriers do not only represent non-BIM adoption, but it also means ineffective-BIM adoption. The findings of this research suggest that both non-BIM adoption and ineffective-BIM adoption will be resolved through the intense use of BIM motivation strategies and BIM utilization strategies. This explanation is meaningful because non-BIM adoption (which pertains to barriers against preliminary BIM adoption) would be significantly reduced due to the use of BIM motivation strategies. As conceptualised in this research, BIM motivation strategies provide social, normative, and coercive forces that can be employed to reduce non-BIM adoption among the construction organisations.

Equally, ineffective-BIM adoption (which pertains to barriers against sustained BIM adoption) would significantly decrease due to the use of BIM utilisation strategies. BIM utilisation strategies comprise of variables that describe the proper and effective application of BIM on construction projects. The finding that BIM motivation strategies and BIM utilisation strategies are the leading BIM implementation strategies in the reduction of barriers against preliminary and sustained BIM adoption is unexpected. The conclusions by Chan et al., (2019) and Liao and Teo (2018) provide support for the nature and strength of association between BIM implementation strategies and BIM adoption barriers as found in this research. The model is useful in determining the necessary changes in plans and policies for driving BIM adoption in the construction industry.

The model provides theories on how to eliminate BIM adoption barriers, and how to identify supports and information that are required for BIM adoption. The model also provides insights into how to make BIM implementation to function effectively. The model will benefit more from the inclusion of other forms of BIM adoption barriers. Insights from a study that will identify new BIM adoption barriers through a relevant theoretical perspective will greatly benefit the understanding of the relationship between BIM implementation strategies and BIM adoption barriers.

6.6.3 Relationship between a reduction in barriers to BIM adoption and the level of BIM adoption on construction projects.

A hypothesised model (Hypothesis 5) that suggested a reduction in barriers against preliminary and sustained BIM adoption has a positive significant impact on the level of BIM adoption on construction projects was tested. The model had five hypothesised relationships, which were all reliably supported by the results of the structural equation modelling. The results show that the models have an acceptable validity, which means that the hypothesised relationships were significant, and that there is a positive association between the constructs in the model. The findings confirm that as the rate of reduction of barriers against preliminary and sustained BIM adoption increases, the extent of BIM adoption on construction projects increases. This means that the level of BIM adoption on construction projects depends on the rate of reduction in barriers against BIM adoption.

It also means that the BIM adoption barriers were properly defined and identified and, therefore, efforts made at reducing them are yielding positive results. These positive results are the visible and practical BIM adoption on construction projects. More interrogation of the findings reveals that the strength of association between the rate of reduction in BIM adoption barriers, and the extent of BIM adoption is weakly positive. This indicates that there is a causation between the two constructs, but that the causation is not reliable. This form of the relationship suggests that the rate of reduction in BIM adoption barriers does not fully and solely account for the extent of BIM adoption on construction projects. Another explanation for the findings may be that the forces causing a reduction in BIM adoption barriers are not sustainable and strong. This calls for caution in relying on a reduction in BIM adoption barriers against automatically translate to BIM adoption on construction projects.

In this research, the level of BIM adoption on construction projects was conceptualised using BIM performance assessment criteria, BIM tools employed, BIM capacity utilised, types of building information models developed, and level of clarity of objects that were used to develop building information models. The results of the model estimation show that BIM performance assessment criteria, BIM tools employed, and level of clarity of objects that were used to develop building information models were strongly associated with a reduction in the barriers against BIM adoption. The types of building information models developed and BIM capacity utilised had a moderate association with a reduction in BIM adoption barriers. These findings suggest that a reduction in BIM adoption barriers can be relied on to bring about the use of various types of BIM tools on construction projects, the specification of details of the building information models that would be developed for construction projects, and the evaluation of BIM performance on construction projects.

As a result of a reduction in the barriers against BIM adoption, the development of different types of building information models for construction projects, as well as the utilisation of BIM capacity for construction projects cannot be guaranteed. This is a reasonable explanation, because the fact that BIM adoption barriers have reduced does not mean that all the types of building information models will be developed for every construction project. It also does not mean that all the construction organisations and professionals in the construction industry will have BIM skills and competence. This is because certain old construction professionals many assume or conclude that it is too late for them to be BIM-compliant, while certain construction organisations may decide to outsource BIM roles and responsibilities to the BIM consultants and experts. There may even be some construction organisations that will be limited in their scope of work, or who are financially incapable of acquiring BIM capacity. For instance, a small construction organisation with specialisation in residential buildings might not have the financial capability for, or see the need for, BIM capacity. The model gives useful evidence regarding the postulations on the effects of a reduction in BIM adoption barriers on widespread BIM adoption. The evidence provided by the model extends the postulations on the strategies for driving BIM adoption. Also, the findings of this research promote the need to reduce BIM adoption barriers and the implications for such reduction.

6.6.4 Relationship between BIM implementation strategies, reduction in barriers to BIM adoption, and the level of BIM adoption.

It was hypothesised in this research (Hypothesis 3) that the positive and significant relationship between BIM implementation strategies and the level of BIM adoption on construction projects is mediated by a reduction in barriers against preliminary and sustained BIM adoption on construction projects. The explanatory power of the parameter estimates from the structural equation model fully and reliably validated the hypothesis in the model. This suggests that a reduction in BIM adoption barriers played a positive and significant role in the positive and significant relationship between BIM implementation strategies and the level of BIM adoption. The findings specifically revealed a strong positive association between a reduction in BIM adoption barriers and the level of BIM adoption on construction projects. A weak positive association was found between BIM implementation strategies and the level of BIM adoption on construction projects.

It was also found that a moderately positive relationship existed between BIM implementation strategies and a reduction in BIM adoption barriers. These findings suggest that a significant reduction in BIM adoption barriers must take place before the level of BIM adoption on construction projects can be controlled by the BIM implementation strategies. It means that the use of BIM implementation strategies must first bring about a reduction in BIM adoption barriers before it can lead to a significant BIM adoption on construction projects. It emerged that the use of BIM implementation strategies might drive BIM adoption, but the main focus of, and objective of, these strategies must be a reduction in BIM adoption barriers. A possible explanation for this relationship is the postulation that BIM implementation is a process. In the BIM implementation process, a reduction in BIM adoption barriers must occur before BIM adoption on construction projects can be visible and widespread.

As illustrated in Figure 6.9, all the BIM implementation strategies (BIM commitment, BIM motivation, BIM capacity development, and BIM utilisation strategies) showed a moderately positive association with a reduction in BIM adoption barriers and the level of BIM adoption on construction projects. This reveals that none of the BIM implementation strategies that are employed have the required intensity to simultaneously create a reduction in BIM adoption barriers and lead to BIM adoption on construction projects. This means that BIM implementation strategies only cause a slight reduction in BIM adoption barriers. This explains the low level of BIM adoption on construction projects in South Africa. Likewise, Figure 6.9 demonstrates that all the sub-constructs for BIM adoption on construction projects (BIM performance assessment criteria, BIM capacity utilised, BIM tools employed, types of building information model developed for the projects, and the level of clarity of objects that were used to develop building information model) display a moderately positive association with a reduction in BIM adoption barriers and BIM implementation strategies. This implies a low level of BIM adoption on construction projects. The level of BIM adoption on construction projects is a response to, or the result of, the level of reduction in BIM adoption barriers and perhaps the efficiency or level of use of the BIM implementation strategies. These findings show a corresponding movement in the level of BIM adoption on construction projects and the level of efficiency or level of use of the BIM implementation strategies. These findings imply that the aggressive use of BIM implementation strategies, or the use of effective BIM implementation strategies, will create an intensive and widespread adoption of BIM on construction projects. This correlation is subject to the rate of reduction in BIM adoption barriers, and finds support in the conclusions of previous studies by Herr and Fischer (2019) and Zhou and Yang (2019).

The findings of this research have numerous implications for BIM implementation. First, the model that was tested in this research establishes a reduction in BIM adoption barriers as an intermediate requirement before a visible and widespread adoption of BIM on construction projects. Second, the model identifies the variables that are directly involved in the BIM adoption and implementation process. Third, the model describes and validates the mechanisms for initiating the BIM implementation process. Fourth, the model provides an understanding of important relationships and principles in the BIM implementation process.

6.6.5. Relationship between the level of BIM adoption and the levels of integration and collaboration.

A hypothesised model suggesting that there is a positive and significant relationship between the level of BIM adoption on construction projects and the levels of integration and collaboration among the BIM supply chain members was tested (Hypothesis 4). Twenty (20) hypothesised relationships were identified in the model and all were statistically significant and fully validated. The findings show that the path analysis from the level of BIM adoption on construction projects to the levels of integration and collaboration among the BIM supply chain members was strongly positive and significant. This means that both constructs moved in the same strength and direction.

In other words, the extent of integration and collaboration among the organisation and professionals that are participating in BIM-based construction projects can be controlled by the intensity of BIM adoption on construction projects. Lack of cooperation, teamwork, support, trusts, open communication, and shared interests have become commonplace in the relationships among the project participants or team that is partaking in non-BIM-based construction projects. This was unacceptable to project success and the growth of the construction industry. BIM adoption on construction projects was introduced to the construction industry to resolve the lack of integration and collaboration among the project participants, and other challenges that characterised project delivery (Yusuf *et al*., 2016; Getuli *et al*., 2016). Thus, the findings of this research, which indicated that BIM adoption on construction projects had a positive and strong effect on the occurrence of cooperation, support, trust-based relationship, and teamwork among the project participants, was as expected.

The findings of this research also indicate that utilisation of BIM capacity, usage of BIM tools, and the development of building information models had a moderately positive association with the level of integration and collaboration among the BIM supply chain members. A strong and positive association was found between BIM performance assessment criteria, levels of clarity of objects that were used to develop building information models, and the levels of integration and collaboration among the BIM supply chain members. These findings suggest that the efforts made by the BIM supply chain members towards ensuring the success of the BIM-based projects, and to meet the information demands of one another towards the development of discipline-specific building information models, contributed more to the levels of integration and collaboration among the members. This explanation is understandable, because the demand for and supply of information fosters teamwork and cooperation (Papadonikolaki et al., 2016; Alreshidi *et al.*, 2017).

Similarly, members' shared interests will result in mutual efforts to ensure the success of BIM adoption on the projects. The tenable explanation for the moderate effect of BIM capacity utilisation, use of BIM tools, and development of building information models on the level of occurrence of integration and collaboration among the members may be that these features of BIM adoption on construction projects benefit the team members more than they benefit the team as a whole.

Also, the findings show that all the sub-constructs for the level of integration and collaboration among the BIM supply chain members (trust-based relationships, information sharing and exchange, network communication, and knowledge sharing and transfer) have a moderately positive association with the level of BIM adoption on construction projects. This is an indication that the level of BIM adoption was not advanced enough to give rise to a high degree of trust-based relationship, information sharing and exchange, knowledge sharing and transfer, and network communication. The findings of this research confirm a moderate association between the level of BIM adoption and levels of integration and collaboration among the BIM-SCM. This is due to the level of BIM adoption on construction projects in South Africa. This explanation corresponds with the conclusion by Kong et al., (2020) and Trach et al., (2020), which indicated that there are struggles in sharing and integrating building information models from different disciplines, because, at a lower level of BIM adoption, BIM has little or no impact on construction projects and team performance.

The findings of this research are also in line with the general and specific conclusions of similar studies on the effects of BIM adoption on integration and collaboration development among the BIM-SCM (see Liao and Teo, 2018; Koseoglu and Nurtan-Gumes, 2018; Kouhestani and Nik-Bakht, 2020; Zhai et al., 2019; Utkucu and Sozer, 2020; Hatem et al., 2018; Liu et al., 2017; Ozturk, 2019; Poirier et al., 2017; Liu et al., 2017). In terms of the general effects of BIM adoption, Ozturk (2019) indicated that the application of BIM on construction projects brings about knowledge acquisition, willingness to share information, and effective communication as a result of the interactive working platforms that BIM provides. Liu et al. (2017) concluded that BIM adoption on projects fosters connections and collaboration among the project participants. Regarding specific effects of BIM adoption, for example information sharing and exchange, Ozturk (2019) concluded that the use of BIM on construction projects leads to the development and exchange of accurate, clear, and complete information. Poirier et al. (2017) inferred that BIM adoption on construction projects redefines the collaborative relationships among the project participants, such as information flow.

Hatem et al. (2018) inferred that BIM adoption on projects enables the project participants to have access to information in real-time. Kouhestani and Nik-Bakht (2020) maintained that BIM fosters timely information exchange. Regarding knowledge sharing and transfer, Ozturk (2019) concluded that project participants can get reliable knowledge for quick decision-making as a result of the use of BIM on construction projects. Concerning trust-based relationships, Utkucu and Sozer (2020) inferred that with BIM adoption on projects, project participants have no difficulties in trusting each other. Also, in relation to network communication, Zhai et al. (2019) inferred that BIM adoption enables real-time communication and frequent interactions among the project participants, while Hatem et al. (2018) concluded that the level of communication among the BIM-SCM improves when BIM is adopted for construction projects, because BIM makes communication to be direct and open.

The findings of this current research suggest that there is a need to intensify the extent of BIM adoption on a construction project in order to realise the full benefits of BIM adoption. This calls for the need to redefine or extend the concept of BIM adoption on construction projects. The redefinition and extension must incorporate more of the BIM process, protocols, and principles, rather than simply relying on BIM tools and technologies. BIM processes, protocols, and principles directly address relational challenges such as lack of teamwork, cooperation, and trust, and they, therefore, greatly benefit the BIM supply chain when used correctly. The major significance of the findings of this research is that it theorises which BIM adoption system will yield high levels of collaboration and integration among the BIM supply chain. The research also theorises on the constituents of integration and collaboration among the BIM supply chain members. Evidence for the impact of BIM adoption on project success was provided by the findings in this research.

6.6.6 The interactions between the BIM implementation stages (Hypothesis 6a).

This research tested a hypothesised model (Hypothesis 6a) that theorised a positive and significant interaction between the levels of integration and collaboration among the BIM supply chain members, the level of BIM adoption on construction projects, BIM implementation strategies in use, and a reduction in barriers against preliminary and sustained BIM adoption on construction projects. The explanatory power of the parameter estimates of the structural equation model validated the hypothesis in the model. The parameter estimates show that the BIM implementation strategies in use were very strongly associated with a reduction in barriers against preliminary and sustained BIM adoption on construct projects, and strongly associated with the level of BIM adoption on a construction project. These associations were significant and positive as postulated in the hypothesised model. A positive but moderate association was found between a reduction in barriers against preliminary and sustained BIM adoption on construction projects and the level of BIM adoption on construction projects.

The path analysis from the level of BIM adoption on construction projects to the levels of integration and collaboration among the BIM supply chain members was strongly positive and statistically significant. These findings confirm that BIM implementation is a process where the interplay between the implementation stages is imperative to the success of the implementation process. The constructs in the hypothesised model stand for the implementation stages that are imperative to the BIM implementation process. The reciprocal influence between these implementation stages is the force that will ensure the smooth flow and success of the BIM implementation process. The findings on the strength of the association between the constructs suggest that there is an inadequate interplay between a reduction in BIM adoption barriers and the level of BIM adoption on construction projects.

Based on the strength of the relationship between the BIM implementation strategies in use and a reduction in BIM adoption barriers, it can be inferred that intense use of the BIM implementation strategies will increase the rate of reduction in BIM adoption barriers, which in turn will strengthen the interplay between a reduction in BIM adoption barriers and the level of BIM adoption on construction projects. The moderate strength of association of the sub-constructs for the BIM implementation strategies (BIM commitment, BIM motivation, BIM capacity development, and BIM utilisation strategies) provides support for the use of BIM implementation strategies on a low-key basis. It seems that the authorities and policymakers in the South Africa construction industry are not aware of the essential importance and meaning of BIM implementation. Another reason for this may be that BIM implementation is still in its early stages in South Africa, and the expected strength of interactions between the implementation stages may not be evident at the early stages.

Regarding the sub-construct for the level of BIM adoption on construction projects, the findings show that BIM performance assessment criteria, BIM tools employed, types of building information models developed, and the level of clarity of objects that were used to developed building information models have a strong association with the other constructs in the model. BIM capacity utilised on the BIM-based projects was found to have a moderate association with the other constructs in the model. This implies that the BIM implementation strategies in use, and the resulting reduction in BIM adoption barriers, bring about the assessment of BIM performance on projects and the development of detailed and appropriate building information models for the projects. As suggested by the findings, BIM capacity was not utilised at the appropriate and required level. This may be as a result of the improper and inadequate use of BIM implementation strategies. Or, it may be as a result of scarcity of BIM skills and competencies in the South African construction industry.

Concerning the sub-constructs for the levels of integration and collaboration among the BIM supply chain members, only information sharing and exchange were found to have a strong association with the other constructs in the model. A moderate association was found between the following constructs in the model: trust-based relationship, knowledge sharing and transfer, and network communication. This finding implies that, in the positive interplay between the constructs, information sharing and exchange occurred more than the other sub-constructs for the levels of integration and collaboration. This finding was expected, because information sharing and exchange are the fundamentals of collaborative interactions. It is also a basic and important requirement for the integration of project information. This means that BIM implementation is at the early stage and over time the full benefits of BIM adoption will be realised. This research has demonstrated the usefulness of implementation process theory for a successful BIM implementation.

The model that was tested in this research identifies the variables that have a positive influence on BIM implementation. The model has also provided information on how to prevent uncertainties and tension in the BIM implementation process, as well as how to facilitate positive interplay between the BIM implementation stages. In addition, the postulations that were validated in the model can be used to improve the strength of interactions between the BIM implementation stages. The deductions from this research are in line with the studies by Lindblad and Guerrero (2020) and Kong et al., (2020) which posit that BIM implementation is a process and that BIM adoption will be more beneficial when its implementation has matured or existed for a longer period.

6.6.7 The interactions between the BIM implementation stages (Hypothesis 6b).

It was hypothesised in this research (Hypothesis 6b) that there are essential BIM implementation strategies that will play an important role in creating a positive interconnection between the levels of integration and collaboration among the BIM supply chain members, the level of BIM adoption on construction projects, and a reduction in BIM adoption barriers. A hypothesised model was developed to test this hypothesis using structural equation modelling. The predictive power of the structural equation model shows an acceptable validity for the hypothesis. The findings show a positive interaction among the constructs together with their sub-constructs. The level of BIM adoption on construction projects show a strong association with the required BIM implementation strategies and the levels of integration and collaboration among the BIM supply chain members.

It emerged that a reduction in BIM adoption barriers has a moderate interconnection with the level of BIM adoption on construction projects. The interaction between the required BIM implementation strategies and a reduction in BIM adoption barriers was found to be very strong. This finding indicates that the use of essential BIM implementation strategies will vigorously reduce the BIM adoption barriers, but it will take time before the level of BIM adoption on construction projects will significantly increase. This means that type and number of construction projects to be executed in the construction industry will determine the level of BIM adoption on construction projects in the industry. In a situation where the economic situation does not encourage the initiation and execution of construction projects, there will not be the need for BIM adoption regardless of the use of essential BIM implementation strategies or a significant reduction in BIM adoption barriers.

Likewise, the use of essential BIM implementation strategies will not bring about a significant reduction in the barriers against BIM adoption in the construction industry where most of the construction projects are small in size, non-complex, and devoid of project expectations that pertain to the benefits of BIM adoption. In these instances, BIM adoption will not be intense or widespread irrespective of the level of reduction in BIM adoption barriers as a result of the use of essential BIM implementation strategies. This finding is significant for the construction industry of developing countries. It suggests that the choice of BIM implementation strategies in the construction industry must be determined based on the contextual needs of the construction industry.

The findings also indicate that there was a moderate association between the constructs and the sub-constructs of the required BIM implementation strategies (BIM commitment, BIM motivation, BIM capacity development, and BIM utilisation strategies), the sub-constructs of the level of BIM adoption on construction projects (BIM capacity utilised, BIM tools employed, level of clarity of objects that were used to develop building information models, types of building information model developed, and BIM performance assessment criteria), and the sub-constructs of the levels of integration and collaboration among the BIM supply chain members (knowledge sharing and transfer, information sharing and exchange, trust-based relationship, and network communication).

These findings suggest that, regardless of the use of essential BIM implementation strategies and its positive role in creating a successful and significant BIM implementation, it will take time before a significant level of BIM adoption will be experienced and before significant levels of integration and collaboration will occur among the BIM supply chain members. Another explanation for the findings may be that the level of BIM adoption complies with the number and type of projects that require BIM adoption. This explanation suggests that the use of essential BIM implementation strategies should be moderate because the aggressive use of the essential BIM implementation strategies will not translate to a high level of BIM adoption. The type of projects that might determine the level of BIM adoption on construction projects will also determine the levels of integration and collaboration among the BIM supply chain members. This is because not all project types require BIM adoption and, for such projects, there will not be a need for integration and collaboration that BIM adoption brings.

Integration and collaboration will only occur among the teams or professionals that participate in the fewer projects that require BIM adoption. This finding signifies that BIM adoption might have become essential for every construction industry, but BIM implementation that will drive it needs to be tailored to the respective needs, characteristics, structure, and requirements of the construction industry. The finding of this research is aligned with the postulations in previous studies by Al-Yami and Sanni-Anibire (2019), Sarvari et al., (2020), Papadonikolaki (2017), and Liu et al., (2017). The model of the interactions between the BIM implementation stages (the levels of integration and collaboration among the BIM supply chain members, the level of BIM adoption on construction projects, reduction in barriers against preliminary and sustained BIM adoption on construction projects, and the required BIM implementation strategies) as tested in this research suggests several plans and policies for achieving an efficient and effective BIM implementation. It also provides information on how to prioritise the BIM adoption goals. Another important practical implication of the model is its postulations on the benefits of reconciling the needs of the construction industry with the choice of BIM implementation strategies.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter presents the summary of the research questions, results and findings, conclusions on findings, contribution to knowledge, recommendations, and areas for further research.

7.2 Summary of key findings

This research aimed to examine the barriers against BIM adoption on construction projects, and to investigate whether there are specific BIM implementation strategies that will bring about sustained BIM adoption practices and the best levels of integration and collaboration among the BIM supply chain members. This aim was achieved through the research objectives that were identified according to the stages that are included in the BIM implementation process, as explained in the theoretical framework for the research. The first objective was to identify the BIM implementation strategies in use. The establishment of the indicators of a reduction in barriers against preliminary and sustained BIM adoption on construction projects was the second research objective.

Establishment of the level of BIM adoption on construction projects in terms of project size and complexities, BIM tools, BIM technologies, BIM capacity, information management, BIM process, and project performance assessment was the third research objective. The fourth research objective was to determine the levels of integration and collaboration among the BIM supply chain members. The fifth objective was to model the interactions between the levels of integration and collaboration among the BIM supply chain members, the level of BIM adoption on construction projects, reduction in barriers against preliminary and sustained BIM adoption on construction projects, and BIM implementation strategies.

To achieve the fifth objective, relationships and interactions between the stages contained in the BIM implementation process were modelled as follows: determination of the relationship between BIM implementation strategies and the level of BIM adoption on construction projects, determination of the relationship between BIM implementation strategies and barriers against preliminary and sustained BIM adoption on construction projects, ascertaining whether BIM implementation strategies and a reduction in barriers against preliminary and sustained BIM adoption on construction projects affect the level of BIM adoption on construction projects, and establishing whether the level of BIM adoption on construction projects affects levels of integration and collaboration among the BIM supply chain members.

The key findings from the investigation of these objectives are presented in the following sub-sections.

7.2.1 Objective 1: Identify the BIM implementation strategies for driving BIM adoption on construction projects.

This research has shown that formal and informal BIM capacity development strategies, such as BIM workshops, BIM seminars, corporate BIM training, and BIM education, were already in use in the South African construction industry. It was also found that strategies for BIM utilisation include the consideration of the appropriate form of collaboration required for projects, the consideration of appropriate import and export file format for projects, consideration of the appropriate BIM maturity levels for projects, and consideration of the appropriate level of development for building information models.

The required BIM implementation strategies were found to be mixed-approach based (that is, government-driven and private driven). It was made known in the research that the BIM implementation strategies that are essential to a significant reduction in the barriers against preliminary and sustained BIM adoption, as well as the widespread adoption of BIM adoption on construction projects, are the development of a BIM-friendly organisational structure and culture, provision of in-house BIM training, development of a BIM management process, adoption of BIM as a marketing strategy, BIM education and training, BIM adoption support funds, development of guidelines on BIM roles and responsibilities, and strategic planning of BIM adoption on projects.

7.2.2 Objective 2: Establish the indicators of a reduction in barriers against preliminary and sustained BIM adoption on construction projects.

This research has shown that the lack of BIM capacity, lack of understanding of BIM concepts, and lack of enforcement from the government were the major barriers against preliminary BIM adoption in the South African construction industry. Non-management of BIM adoption on construction projects and lack of understanding and information on BIM tools and technologies were found to be the major barriers against sustained BIM adoption in the South African construction industry. The second most important finding was that the BIM implementation strategies in use are private driven, and have a low impact on the BIM implementation stages. The possibility of getting high-value clients, the quest for a competitive edge, the need for technological sophistication, and the need to be socially acceptable to the clients were found to be providing motivations for BIM adoption. Top management of construction organisations were found to be committed to the education of staff on BIM potentials, incorporation of BIM adoption into the vision of the organisations, and development of BIM capabilities as new values in their organisations.

The evidence from this research suggests that the traditional BIM adoption barriers, such as copyright issues, lack of BIM resources, and non-readiness of employees to accept changes, have significantly reduced.

7.2.3 Objective 3: Establish the level of BIM adoption on construction projects.

Regarding the level of BIM adoption on construction projects, the research has shown that fewer building information models were developed for projects, BIM performance assessment was not intensive, the emphasis was not placed on the level of objects' clarity of building information models, BIM skills and competencies were insufficient, and BIM management was disorganised and unplanned.

The strategic planning for BIM adoption on projects was found to entail the use of Computer-Aided-Design experience and competence in BIM design process, use of BIM-friendly conventional procurement systems, utilisation of popular BIM software technologies (Revit and ArchiCAD), regulation of the quality and contents of building information models via the level of development, and evaluation of project complexity for BIM adoption.

7.2.4 Objective 4: Determine the levels of integration and collaboration among the BIM supply chain members (BIM-SCM).

As regards the level of integration and collaboration among the BIM-SCM, the findings of this research revealed that the BIM-SCM is developing and sharing high-quality project information, engaging in multi-dimensional flow of information, and gathering BIM knowledge from BIM standards, BIM experience, and BIM training. In addition, the research has shown that BIM process requirements are causing the BIM supply chain members to be open in sharing information, to be cooperative, to trust the problem-solving ability of one another, and to trust the competence and perspectives of one another.

7.2.5 Objective 5: Model the interactions between the BIM implementation stages.

As regards the association between BIM implementation strategies and BIM adoption on construction projects, it was found that BIM motivation and BIM utilisation strategies have greater impacts on BIM adoption on construction projects. The use of BIM tools and levels of development were found to contribute more to BIM adoption on construction projects. The findings of the research pointed out that in the relationship between BIM implementation strategies and the BIM adoption barriers, the noticeable impacts of BIM implementation strategies on the BIM adoption barriers are as a result of the effectiveness of the BIM implementation strategies in use. The research established that the rate of reduction in BIM adoption barriers is not in tandem with the extent of BIM adoption on construction projects. The research has shown that the rate of reduction in BIM adoption barriers does not guarantee a corresponding rise in the development of different types of building information models and the utilisation of BIM capacity. This was found to be due to the scarcity of BIM skills and competencies as well as a lack of understanding of the use of BIM tools.

It emerged that BIM implementation strategies can be used to control the impacts of a reduction in BIM adoption barriers on the extent of BIM adoption, and that there is a moderate reduction in BIM adoption barriers and low level of BIM adoption on construction projects because the appropriate BIM implementation strategies are not in use. The research finding has shown the effects of the level of BIM adoption on integration and collaboration

among the BIM-SCM by highlighting that the extent of integration and collaboration among the BIM-SCM is governable by the intensity of BIM adoption on construction projects. Additionally, the research findings show that cooperative behaviours such as cooperation, trust, support, and teamwork occurred among the BIM-SCM as a result of BIM adoption on construction projects. It also revealed that the demand and supply of information among the BIM-SCM, as well as the desire for the success of BIM adoption on construction projects, contribute more to the occurrence of integration and collaboration among the BIM-SCM.
With regard to the interactions between the stages in the BIM implementation process (*BIM implementation strategies, reduction in barriers against preliminary and sustained BIM adoption, levels of BIM adoption on construction projects, and levels of integration and collaboration among the BIM supply chain members (BIM-SCM)*), the findings revealed that the success of the BIM implementation process depends on a positive interplay between the interacting implementation stages. The findings also revealed that the BIM implementation strategies that are employed did not possess the required force and intensity to strengthen the positive interplay between the interacting implementation stages.

Regarding the input of the essential BIM implementation strategies (*that is, the BIM implementation strategies that are required for driving BIM adoption on construction projects*) in the BIM implementation process, it emerged from the findings that the use of essential BIM implementation strategies will effectively drive a successful BIM implementation process. The findings indicated that the essential BIM implementation strategies will accelerate the reduction of the barriers against BIM adoption, but will not accelerate BIM adoption on construction projects. This is because the acceleration of BIM adoption on construction projects may not be appropriate for all construction organisations and construction projects. Likewise, integration and collaboration will only occur among the BIM-SCM for the projects that require BIM adoption.

7.3 Conclusions

The results of this research indicate that efforts are required to ensure that construction stakeholders in South Africa understand the BIM concept and develop BIM skills and competencies. It was established in this research that the quest for a competitive edge is driving BIM adoption among the construction organisations in South Africa; however, working policies and legislation on BIM adoption are required to drive a successful BIM implementation. Also, it can be inferred that construction organisations are struggling with the usage of BIM at various project stages and on subsequent projects, because BIM managers or BIM consultants were not adequately engaged to coordinate the process of BIM adoption as well as provide information on the use and application of BIM tools and technologies.

Deductions from this research suggest that construction organisations are implementing BIM because they want to improve the quality of their profiles and performances, as well as to compete for clients and relevance in the South African construction industry. The construction organisations had identified BIM implementation and adoption as their future objectives. The strategies in use for developing BIM capacity in the construction organisations are suitable for organisational growth and development. It was also deduced that BIM adoption (a BIM execution plan) must integrate BIM goals and objectives with project expectations. This research enabled the understanding that employees in the construction organisations are ready to acquire BIM skills, and that the construction organisations are acquiring BIM infrastructures.

This research postulates that BIM adoption on construction projects in South Africa is still at an elementary stage, because the benefits of BIM adoption are still unpronounced, because BIM skills and competence were at a functional level, because there are a lack of skills and experience of BIM management, and because there is a predominant lack of understanding of what BIM adoption on projects entails. The level of occurrence of integration and collaboration among the BIM-SCM was low because the BIM-SCM exhibited some measures of competing interests, professional stereotypes, uncooperative behaviours, and risk shifting. Furthermore, the findings in this research bring about the deduction that BIM implementation is beyond statutory regulations. It requires the introduction of BIM roles and responsibilities in construction organisations, goal setting, resource allocation, identification of Key Performance Indicators, strategic planning and management, funding, and continuous development. Concerning the strategic planning of BIM adoption on construction projects, this research inferred that BIM adoption plans must consider the utilisation of the existing BIM competence, existing BIM-friendly procurement systems, project complexity, and project expectations.

The findings on the interactions among the stages in the BIM implementation process allow this research to advance that the top management of construction organisations and the industry stakeholders are paying inadequate attention to BIM capacity development and BIM commitments. The impact of BIM implementation strategies on the BIM adoption barriers is insignificant, because the use of BIM implementation strategies is in the early stage. Similarly, it was inferred that a significant reduction in BIM adoption barriers may not generally bring about a significant extent of BIM adoption on construction projects. However, it will lead to a significant usage of BIM tools, level of development, and BIM performance assessment criteria. This means that the BIM implementation strategies must be developed to have dual objectives of simultaneously triggering a reduction in BIM adoption barriers and instigating a widespread BIM adoption on construction projects. Additionally, it can be postulated that BIM-SCM benefits more individually from the use of BIM tools and technologies, while they benefit more collectively from the use of BIM processes and principles. In reality, a high level of integration and collaboration among the BIM-SCM will be realised when BIM adoption hinges more on the use of BIM processes and principles.

Finally, this research asserts that the essential BIM implementation strategies are not in use, while the BIM implementation strategies in use are not appropriately and effectively employed. The choice and development of BIM implementation strategies to drive a widespread BIM adoption must reflect the characteristics of the construction industry and construction projects. This is because the nature and structure of the construction industry, as well as the type and number of projects that require BIM adoption, have a huge impact on the determination of the level of BIM adoption.

7.4 Recommendations

The evidence from this research leads to the recommendation that construction organisations in South Africa need to develop a preliminary BIM adoption plan. This must be developed to address the barriers against preliminary BIM adoption. Equally, construction organisations in South Africa must appoint BIM consultants or designate BIM managers and BIM champions in their organisations in order to ensure a sustained BIM adoption. For continuous improvement of BIM adoption on projects, BIM performance assessment must be prioritised. Likewise, organisational vision, mission, and values must be used by top managers of construction organisations in South Africa to drive BIM adoption in their organisations, while the government must make policies to drive BIM implementation.

BIM seminars and workshops create learning opportunities for professionals; therefore they should be focused on impacting the knowledge of BIM concepts and BIM applications.

Relatedly, the following approaches must be employed to increase the level of BIM adoption on construction projects: developing methods and metrics for assessing BIM performance, improving upon the existing BIM skills and competencies, and laying emphasis on BIM management skills. This calls attention to the importance of appointing BIM managers for BIM-based construction projects, and the need for the BIM managers to develop a BIM adoption or execution plan that focuses more on achieving the core features of integration and collaboration among the BIM-SCM. BIM must not be adopted on projects without a strategic and contingent BIM adoption plan and a BIM adoption risk management plan. In the same way, project characteristics and expectations must guide the strategic planning for BIM adoption.

Finally, the findings of this research have informed the following noteworthy recommendations:

- BIM adoption should be used as one of the criteria for grading successful and high-performing organisations,
- BIM motivations and BIM utilisation strategies must be used intensely so as to eliminate the barriers against BIM adoption,
- The development of BIM capacity should be given precedence to above the efforts at reducing the barriers against BIM adoption,
- BIM implementation strategies that can concurrently reduce the barriers against BIM adoption and bring about a widespread BIM adoption on projects must be aggressively and effectively employed,
- The system of BIM adoption on construction projects must be re-conceptualised and must focus more on the use of BIM processes and principles than the use of BIM tools and technologies, and
- The choice of essential or required BIM implementation strategies must be based on the needs and requirements of the construction industry.

7.5 Contributions to knowledge

This research has provided new inferences and an in-depth understanding of the BIM implementation process, and contributed to theories on the relationship between BIM implementation strategies and a reduction in barriers against preliminary and sustained BIM adoption on construction projects. It has made available new insights on the structures and stages of the BIM implementation process, and has offered new postulations that will aid the comprehension of the interconnections between BIM implementation strategies and reduction in barriers against preliminary and sustained BIM adoption on construction projects. More importantly, this research has extended the existing theories on BIM adoption and the interactions between the level of BIM adoption on construction projects and levels of integration and collaboration among the BIM-SCM.

Practically, the findings of this research will provide support for the top management of construction organisations in South Africa in understanding the BIM commitments and capacity development requirements for BIM adoption in ther organisations. Also policy-making on BIM motivations for construction organisations and the process of developing BIM guides in South Africa will greatly benefit from the findings of this research.

7.6 Areas for further research

Further work is required to investigate the following:

- The reluctance of the government to embrace BIM implementation and enforce BIM adoption.
- The threats that a lack of trust among construction professionals constitute to BIM adoption.
- The indicators of a reduction in BIM adoption barriers at the project level, organisational level, and industry level. This will provide information on the concentrated strategies that are required to accelerate the reduction rate of the BIM adoption barriers.
- The features of BIM adoption that contribute more to the occurrence of integration and collaboration among the BIM supply chain members.

- The strategies for accelerating a reduction in BIM adoption barriers. This kind of research work will be useful for ensuring a comprehensive and successful BIM adoption.
- The specific benefits of BIM adoption for small construction organisations and old construction professionals.
- The moderating effect of a reduction in BIM adoption barriers on the relationship between the use of BIM implementation strategies and the level of BIM adoption on construction projects using an integrated conceptual model of BIM adoption.
- Framework for achieving high levels of integration and collaboration among the BIM supply chain members through BIM adoption.
- The shortcomings of BIM implementation strategies and the variables militating against them in the BIM implementation process.
- The execution and management of BIM adoption plan on BIM-based construction projects. This kind of investigation will shed more light on the effects of BIM management styles on the level and success of BIM adoption on construction projects.
- The varying strength of the association between the BIM implementation stages.

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APPENDIX A: TABLES FOR CHAPTER SIX

Table 5.3: MIS of responses on BIM motivation strategies that are employed to trigger a reduction in the barriers to BIM adoption.

	BIM motivation strategies employed to trigger a reduction in the barriers to BIM adoption on construction projects	Mean score
1.	Need to improve organizational performance and efficiency in long terms	3.82
2.	Need to improve organizational performance and efficiency in short terms	3.79
3.	Need to improve competitiveness in project bidding	3.76
4.	Need to adapt to global trends	3.73
5.	Need to adapt to global best practices	3.72
6.	The possibility of getting high-value clients	3.60
7.	Prevalent BIM adoption among the top and successful firms	3.56
8.	BIM adoption as a way of supporting development in the construction industry	3.55
9.	Report of BIM usage on a widely acclaimed successful projects	3.55
10.	Need to be seen as being up-to-date and technologically sophisticated	3.55
11.	BIM adoption as part of project team requirement	3.54
12.	BIM adoption among peer firms	3.52
13.	Availability of information on BIM concepts	3.49
14.	BIM adoption as conformity to regulations and rules	3.48
15.	BIM adoption as part of clients' requirement	3.46
16.	Need to be socially acceptable to the clients	3.45
17.	Publication of BIM success stories	3.41
18.	BIM adoption by rival firms	3.37
19.	BIM adoption as a requirement in the company's supply chain network	3.36
20.	Availability of guidelines on BIM roles and responsibilities (BIM supply chain)	3.35
21.	BIM adoption as a marketing strategy	3.32
22.	BIM adoption as a corporate social responsibility strategy	3.31
23.	Advertisement and programs for BIM awareness	3.31
24.	Availability of legalities and copyright ownership of BIM	3.30
25.	Marketing of BIM as professional services	3.30
26.	Availability of guidelines on BIM protocols	3.25
27.	Advocacy and campaign for BIM	3.25
28.	Availability of BIM proficient graduates	3.25
29.	Government-sponsored BIM-based pilot projects	3.22
30.	Availability of fund to assist small and medium firms to adopt BIM	3.22
31.	Availability of national BIM standards	3.21
32.	Mandatory requirement of BIM for building permit application	3.16
33.	Mandatory requirement of BIM in the contractor selection process	3.09

Table 5.4: MIS of responses on BIM commitments that are employed to trigger a reduction in the barriers to BIM adoption.

	Top management commitment strategies employed to trigger a reduction in the barriers to BIM adoption on construction projects.	**Mean score**
1	Coordination of the BIM process in the organization	3.54
2	Educating staff on the potentials of BIM	3.54
3	Introduction of collaborative teamwork culture in the organization	3.53
4	Allowing staff members to participate in the work process redesign process	3.53
5	Development of new values for staff members	3.49
6	Effective communication between stakeholders	3.47
7	Incorporation of BIM into the vision of the organization	3.44
8	Development of communication styles	3.42
9	Development of new management processes	3.41
10	Ensuring effective use of BIM tools	3.41
11	Provision of infrastructures (BIM environment) for BIM	3.39
12	Adaptation of BIM concepts to the organizational culture	3.34
13	Introduction of new roles and job titles	3.34
14	Creation of a new organizational structure	3.34
15	Adherence to the BIM process	3.34
16	Exploration of the usage of BIM on pilot projects	3.33
17	Provision of technical support services in the organization	3.33
18	Appointing BIM champions	3.33
19	An increment in the staff development budget	3.32
20	Provision of in-house BIM training	3.31
21	Documentation of the proceedings of BIM-based projects	3.30
22	Adherence to BIM protocols	3.30
23	Development of performance measures for BIM adoption	3.29
24	Identification of business opportunities in BIM adoption	3.26
25	Facilitate solutions to projects contingencies [incidents and challenges] brought about by BIM adoption	3.25
26	Appointing BIM managers	3.25
27	Stimulating BIM adoption with investments	3.24
28	Anticipating and planning for BIM adoption risk management	3.24
29	BIM consultants engagement	3.23
30	Facilitate solutions to clients contingencies brought about by BIM adoption	3.22
31	Facilitate solutions to organizations contingencies brought about BIM adoption	3.19
32	Provision of incentives for BIM capacity development	3.03
33	Revision of wage structure	2.99
34	Provision of incentives [bonus and allowance] for BIM usage	2.95
35	Revision of the reward system	2.93
36	Sanctions [querries and demotion] for resistance towards BIM usage	2.87

Table 5.5: MIS of responses on BIM capacity development strategies that are employed to trigger a reduction in the barriers to BIM adoption.

	BIM capacity development strategies employed to trigger a reduction in the barriers to BIM adoption on construction projects.	**Mean score**
1	Self-initiated BIM training	3.56
2	BIM workshops	3.55
3	BIM seminars	3.53
4	On-the-job BIM training for the employees	3.53
5	BIM technology educational program in colleges, technical and vocational institutes	3.50
6	BIM application and management program at post-graduate level in the university	3.49
7	BIM education at the undergraduate programme at the university	3.44
8	Corporate BIM training partners	3.42
9	BIM training during Industrial Training/Internship	3.40
10	Peer-group-influenced BIM training	3.39
11	BIM research and development	3.28
12	2D and 3D CAD education in the secondary school	3.22
13	Pre-labour market-influenced BIM training	3.20
14	Upbringing by BIM proficient parents	3.16

Table 5.6: MIS of responses on BIM utilisation strategies that are employed to trigger a reduction in the barriers to BIM adoption.

	BIM utilisation strategies employed to trigger a reduction in the barriers to BIM adoption on construction projects	**Mean score**
1	Determining the appropriate form of collaboration required for the project	3.60
2	Determining the appropriate import and export file format for the project	3.60
3	Determining the appropriate intensity of collaboration required for the project	3.59
4	Determining the appropriate BIM maturity levels [3D, 4D, 5D, 6D] for the project	3.56
5	Determining the appropriate BIM platform for the project	3.56
6	Determining the appropriate collaborative procurement system	3.49
7	Assessing the performance of BIM adoption on the project	3.47
8	Developing digital object identifiers for building materials manufacturers	3.46
9	Determining the appropriate level of development of building information models	3.45
10	Developing digital object identifiers for supply chain	3.40
11	Determining the appropriate types of professionals to form the construction project supply chain network	3.38
12	Determining the appropriate number of professionals to form the construction project supply chain network	3.37
13	Determining the required BIM capacity of the construction project supply chain members based on the project type	3.36
14	Sharing BIM cost and benefits between the client and the supply chain members	3.26

Table 5.7: MIS of responses on the barriers to preliminary BIM adoption.

	Barriers to preliminary BIM adoption on construction projects	**Mean score**
1	The absence of in-house BIM competent professionals	3.55
2	Lack of resources to train employees	3.53
3	Unavailability of BIM competent professionals in the labor market	3.51
4	Lack of cooperation among firms in the industry	3.51
5	Lack of understanding of BIM	3.50
6	Non-communication of BIM concept by relevant industry leadership	3.50
7	Lack of cooperation among professionals in the industry	3.50
8	Lack of BIM awareness among clients	3.50
9	Lack of enforcement from industry leadership	3.48
10	Lack of awareness of BIM	3.47
11	Lack of business case for BIM adoption	3.47
12	Lack of resources to acquire BIM tools and technologies	3.44
13	Lack of enforcement from government agencies	3.41
14	Lack of interests in BIM among clients	3.40
15	Lack of clarity of professional roles in BIM	3.39
16	Satisfaction with existing work methods and process	3.34
17	Lack of trust among firms in the industry	3.31
18	Unavailability of BIM guidelines and standards	3.29
19	Clashes in professional responsibility in BIM	3.27
20	Incompatibility and interoperability of BIM software technologies	3.25
21	Lack of trust among professionals in the industry	3.22
22	Lack of policies and regulations on copyright ownership	3.21

Table 5.8: MIS of responses on the barriers to sustained BIM adoption.

	Barriers to sustained BIM adoption on construction projects	**Mean score**
1	Lack of information on BIM tools and technologies	3.47
2	Top management not engaging BIM consultants to facilitate BIM usage	3.47
3	Lack of understanding and identification of BIM tools and technologies	3.43
4	Failure to understand how BIM adoption will change business processes	3.43
5	Lack of coordination(BIM champion or steering committee) across different supply chain members	3.42
6	Unavailability of BIM infrastructures in the organization	3.38
7	The rigidity of organizational structures	3.38
8	Lack of capacity to meet BIM implementation demands	3.37
9	Unavailability of BIM implementation experts (BIM consultants)	3.36
10	Lack of collaborative teamwork culture in the organization	3.33
11	Lack of a clear strategy for BIM usage on projects	3.33
12	Lack of framework for BIM platforms selection	3.32
13	Lack of coordination(BIM champion or steering committee) across different functional areas	3.31
14	Lack of patience and understanding of the structural changes needed	3.29
15	Skepticism about the benefits of BIM adoption	3.28
16	Employees' unwillingness to accept changes	3.26
17	The perspective of BIM as just a technology	3.26
18	Lack of awareness of the competitive situation of the firms	3.25
19	Lack of patience and understanding of the cultural changes needed	3.23
20	The inadequacy of BIM to support the existing organizational work	3.21
21	The inadequacy of BIM to support the existing business process	3.21
22	The inadequacy of BIM to meet project expectations	3.19
23	Conflict of interests between BIM adoption and organizational vision and objectives	3.16
24	Fear of loss of competitive advantage	3.15
25	Lack of motivation for workers	3.15
26	Inappropriate change management processes	3.10
27	The inadequacy of BIM to meet organizational expectations	3.06
28	The inadequacy of BIM to meet clients' expectations	3.04

Table 5.9: MIS of the responses on the indicators of a reduction in barriers to BIM adoption.

	Indicators of a reduction in barriers to BIM adoption on construction projects.	**Mean score**
1	Acquisition of resources for BIM training of employees	3.48
2	Acquisition of BIM software technologies	3.47
3	BIM-induced changes in construction business process	3.45
4	Availability of BIM infrastructures in the organizations	3.42
5	Availability of policies and regulations on copyright ownership	3.41
6	Employees' readiness to accept changes	3.41
7	Availability of information on the selection of BIM software technologies for projects	3.40
8	Application of BIM tools to projects	3.40
9	Acceptance of BIM as a construction management process	3.39
10	Availability of motivation for workers towards BIM adoption	3.38
11	Evidence of collaborative teamwork culture in the organizations	3.37
12	Acceptance of BIM competency as a competitive advantage	3.36
13	Understanding of roles in BIM adoption by CPSC stakeholder	3.36
14	Regular organization of BIM workshop by regular industry leadership	3.35
15	Availability of national BIM guidelines	3.34
16	Aligning project expectations with BIM potentials	3.34
17	Acceptance of BIM as a work process	3.34
18	Availability of interoperable BIM software technologies	3.33
19	Aligning organizational vision and objectives with BIM adoption	3.33
20	Awareness of BIM by Construction Project Supply Chain (CPSC) stakeholders	3.31
21	Availability of national BIM standards	3.31
22	Awareness of BIM by clients	3.29
23	Understanding of BIM concepts by CPSC stakeholders	3.28
24	Aligning organizational culture with BIM adoption requirements	3.28
25	Understanding of responsibilities in BIM adoption by CPSC stakeholder	3.28
26	Availability of BIM competent professionals in the labor market	3.25
27	Appointment of BIM champion or steering committee	3.25
28	Aligning organizational structures with BIM adoption requirements	3.25
29	Availability of in-house BIM competent professionals	3.23
30	Enforcement of BIM adoption on projects by private clients	3.23
31	Enforcement of BIM adoption on projects by public clients	3.22
32	Enforcement of BIM adoption on public-private projects	3.22

Table 5.10: MIS of responses on criteria for assessing BIM performance on BBCPs.

	Criteria for assessing BIM performance on BIM-based construction projects	Mean score
1	Improved work quality	3.54
2	Improved client satisfaction	3.53
3	Fast project delivery	3.49
4	Effective communication	3.46
5	Broaden the understanding of project needs	3.44
6	Increased knowledge transfer	3.42
7	Improved cooperation	3.39
8	Trust and commitment	3.38
9	Improved professional attitude	3.37
10	Increased information exchange	3.34
11	Improved cost control and management	3.34
12	Improved information quality	3.32
13	Improved safety management	3.32
14	A valued and quick decision-making process	3.32
15	Increased labor productivity	3.31
16	Coordinated decision-making	3.30
17	Allows design review	3.30
18	Improved client participation	3.30
19	Improved schedule management	3.29
20	Improved team culture	3.22
21	Enhanced service quality	3.22
22	Competitive advantage	3.21
23	Provide time database	3.19
24	Eliminate waste	3.18
25	Improved profit margin	3.18
26	Fewer request for information	3.17
27	Reduced contractual claims	3.15
28	Allows clash detection	3.14
29	Intelligent documentation	3.12
30	Improved operation and maintenance of facilities	3.09
31	Improved marketing	3.09
32	Fewer change order	3.07
33	Easy retrieval of building data	3.06
34	Supply chain integration	3.04
35	Integrated and interactive database	3.04
36	Performance simulation	3.02
37	Enables e-procurement of materials and components	2.98
38	Effective supply chain management	2.98
39	Improved energy performance	2.93
40	Improved prefabrication	2.86
41	Enhanced data interoperability	2.85
42	Improved deconstruction management	2.78

Table 5.11: MIS of responses on BIM capacity utilised on BBCPs.

	BIM capacity (BIM skills and competence) utilised on BIM-based construction projects	**Mean score**
1	Competence in 3D CAD tools and software technologies	2.74
2	Information integration skills	2.70
3	Multi-disciplinary collaboration skills	2.63
4	Competence in BIM tools and software technologies	2.62
5	Information exchange skills	2.59

Table 5.12: MIS of responses on BIM tools employed on BBCPs.

	BIM tools employed on BIM-based construction projects	**Mean score**
1	Budget simulation	3.18
2	Construction sequencing	3.15
3	Visualization/rendering,	3.11
4	Life-cycle costing	2.94
5	Clash detections and model checking	2.90
6	Construction simulation	2.89
7	As-built BIM model	2.88
8	Virtual mock-up models	2.87
9	Walkthroughs	2.83
10	Automatic cost data extraction	2.82
11	Automatic quantification	2.82
12	Optimization	2.78
13	3D-object based models	2.77
14	Fabrication models [digital fabrication]	2.72
15	Automatic cost data update	2.71
16	Life cycle analysis	2.66
17	BIM maintenance plans and technical support	2.60
18	Intelligent asset management	2.58
19	BIM embedded operation and maintenance manuals	2.55
20	Detailed energy analysis	2.54
21	Sustainable element tracking	2.53
22	4D scheduling	2.51
23	Conceptual energy analysis	2.51
24	Forensic analysis	2.39
25	LEED tracking	2.38
26	Ground penetration radar conversions	2.34
27	Laser scanning	2.27
28	Animations	2.26
29	CoBie data population and extraction	2.23

Table 5.13: MIS of responses on types of building information models developed for BBCPs.

	Types of building information models developed for BIM-based construction projects	Mean score
1	Construction plan and schedule	3.55
2	Construction health and safety information model	3.41
3	Cost and quantities of information model	3.39
4	Structural information model	3.38
5	Construction system information model	3.36
6	Architectural information model	3.33
7	Electrical services information model	3.20
8	Structural steelwork fabrication information model	3.19
9	Mechanical services information model	3.03
10	Lighting analysis information model	3.00
11	Maintenance and operation schedule	2.93
12	Sustainability analysis information model	2.90
13	Mechanical system ductwork fabrication information model	2.89
14	Energy analysis information model	2.87
15	Pre-cast panels fabrication information model	2.77
16	Glazing system fabrication information model	2.77
17	Curtain walling fabrication information model	2.66
18	Crane assignment information model	2.53
19	Rain screens fabrication information model	2.51

Table 5.14: MIS of responses on the level of clarity of objects that were used to develop building information models for BBCPs.

	Level of clarity of objects that were used to develop building information models for BIM-based construction projects	Mean score
1	G3 – Rendered (description, dimension, manufacturer's details, model's details & image)	3.00
2	G2 – Defined (description, dimension, manufacturer's details & model's details)	2.94
3	G1 – Concept (description & dimension only)	2.78
4	G0 – Schematic (description only)	2.64

Table 5.15: MIS of responses on trust-based relationships among the BIM-SCM.

	Trust-based relationships among the BIM supply chain members	**Mean score**
1	Problem-solving ability	3.85
2	Competence of personnel	3.84
3	Competence of organizations	3.69
4	Consistent integrity	3.66
5	Openness in sharing information	3.65
6	Mutual exchange of ideas	3.59
7	Honesty and mutual commitment	3.55
8	Freedom to state opinions and perspectives	3.51
9	Cross-functional cooperation	3.50
10	Display of confidence for each other by supply chain members	3.50
11	Support for innovation and learning	3.48
12	Shared interests and project expectations	3.47
13	Conflict resolution	3.46
14	Inter-personal relationship	3.43
15	Inter-organizational relationship	3.43
16	Social interaction between supply chain members	3.40
17	Risk sharing	3.40
18	Mutual rewards and benefits	3.40
19	Work interaction between supply chain members	3.39
20	The emotional interaction between the project team	3.35
21	The absence of competing interests	3.29
22	Absence of tribalism	3.28
23	The absence of professional stereotypes	3.27
24	Absence of racism	3.26
25	Compensating for each other’s weaknesses	3.22
26	Persistence of relationship after projects	3.21
27	Non-misuse of information by supply chain members	3.20
28	The absence of defensive behavior	3.18
29	Lack of confrontation and adversarial relationship	3.12
30	Exploiting each other’s strengths	3.11

Table 5.16: MIS of responses on information sharing and exchange among the BIM-SCM.

	Information sharing and exchange among the BIM supply chain members	**Mean score**
1	Information shared is credible	3.73
2	Clarity of information	3.67
3	The high quality of information	3.66
4	Information shared is accurate	3.60
5	Usage of collaborative electronic media for information sharing	3.53
6	Timely sharing of information	3.53
7	Adequacy of information	3.47
8	Enhanced interpersonal sharing and exchange of information	3.46
9	Selection of information sharing channels	3.42
10	Usage of information exchange format for integrating project information	3.39
11	Non-withholding of information	3.35
12	Cross-boundary information sharing/enhanced inter-organizational sharing and exchange of information	3.34
13	Usage of information sharing protocols	3.32
14	Usage of consistent data structures and definitions	3.28
15	Creation of homogeneous or single project information database	3.27
16	The absence of conflicting information	3.22
17	Non-distortion or manipulation of information	3.20
18	Linking and integration of project information/ data federation	3.18
19	Flawless information exchange	3.15
20	File-based data interoperability	3.14
21	Server-based data interoperability	3.09

Table 5.17: MIS of responses on network communication among the BIM-SCM.

	Network communication among the BIM supply chain members	**Mean score**
1	Documentation of communication	3.78
2	Formation of open and formal communication channels	3.76
3	Communication across the stages in the project life-cycle	3.70
4	Regular interpersonal communication	3.66
5	Adoption of common electronic communication platforms	3.64
6	Establishment of a secured line of communication	3.61
7	Usage of communication protocols	3.61
8	Regular team communication	3.58
9	Real-time communication	3.55
10	Feedback communication	3.55
11	Regular inter-group communication	3.53
12	Timely communication	3.51
13	Flexibility of formalities	3.50
14	Regular inter-organizational communication	3.50
15	Positive corporate communication	3.49
16	The multi-directional flow of information	3.48
17	Adoption of joint problem-solving techniques	3.46
18	Reciprocal flow of information	3.39
19	Problem-solving structured e-meeting	3.39
20	Agenda-driven structured e-meeting	3.27
21	Open-ending structured e-meeting	3.24

Table 5.18: MIS of responses on knowledge sharing and transfer among the BIM-SCM.

	Knowledge sharing and transfer among the BIM supply chain members	Mean score
1	Valued decision-making	3.75
2	Understanding of information	3.72
3	Quick decision-making	3.70
4	The high quality of information	3.65
5	Collective decision-making	3.63
6	Willingness to share resources	3.60
7	Inter-personal knowledge sharing	3.60
8	Inter-team knowledge sharing	3.57
9	Usage of collaborative electronic media for knowledge sharing	3.52
10	Identification of clashes and omission in information models	3.49
11	Review of projects after completion	3.48
12	Sharing of knowledge on best practices among the supply chain members	3.48
13	Inter-professional knowledge sharing	3.46
14	Database creation and management	3.45
15	Inter-group knowledge sharing	3.45
16	Knowledge documentation in the form of the project proceeding	3.45
17	Sharing of collaborative experiences among the supply chain members	3.42
18	Extraction of measurement information from the information models	3.41
19	Inter-organizational knowledge sharing	3.40
20	Sharing of project lesson learned among supply chain members	3.40
21	Extraction of cost information from information models	3.34
22	Extraction of installation information from the information models	3.30
23	Sharing of project reviews among supply chain members	3.29
24	Extraction of manufacturer’s details from the information models	3.29
25	Extraction of fabrication information from the information models	3.28
26	Parametric and object-oriented design of information models	3.27
27	Extraction of tendering/bidding information from the information models	3.26
28	Sharing of insights among the supply chain members	3.21
29	Extraction of operation and maintenance information from the information models	3.20

Table 5.19: MIS of responses on BIM commitment strategies that are employed to trigger a reduction in the barriers to BIM adoption.

	BIM commitment strategies that are employed to trigger a reduction in the barriers to BIM adoption on construction projects	**Mean score**
1.	Educating staff on the potentials of BIM	3.77
2.	Provision of in-house BIM training	3.74
3.	Adherence to BIM protocols	3.72
4.	Exploration of the usage of BIM on pilot projects	3.71
5.	Provision of technical support services in the organization	3.71
6.	Development of management processes	3.69
7.	Provision of infrastructures (BIM environment) for BIM	3.67
8.	Effective communication between stakeholders	3.67
9.	Allowing staff members to participate in the work process redesign process	3.67
10.	Development of communication styles	3.67
11.	Introduction of collaborative teamwork culture in the organization	3.66
12.	Adherence to the BIM process	3.66
13.	Documentation of the proceedings of BIM-based projects	3.63
14.	Creation of a new organizational structure	3.63
15.	Adaptation of BIM concepts to the organizational culture	3.61
16.	Ensuring effective use of BIM tools	3.61
17.	Development of new values	3.60
18.	Incorporation of BIM into the vision of the organization	3.59
19.	Anticipating and planning for BIM adoption risk management	3.59
20.	Coordination of the BIM process in the organization	3.57
21.	An increment in the staff development budget	3.57
22.	Identification of business opportunities in BIM adoption	3.57
23.	Facilitating solutions to organizations contingencies of BIM adoption	3.56
24.	Introduction of new roles and job titles	3.55
25.	Appointing BIM champions	3.55
26.	Appointing BIM managers	3.54
27.	Development of performance measures for BIM adoption	3.52
28.	Facilitating solutions to projects contingencies of BIM adoption	3.49
29.	Stimulating BIM adoption with investments	3.49
30.	Facilitating solutions to clients contingencies of BIM adoption	3.48
31.	BIM consultants engagement	3.42
32.	Revision of wage structure	3.40
33.	Provision of incentives [bonus and allowance] for BIM usage	3.35
34.	Revision of the reward system	3.35
35.	Provision of incentives for BIM capacity development	3.34
36.	Sanctions [queries and demotion] for resistance towards BIM usage	3.22

Table 5.20: MIS of responses on BIM motivation strategies that are required to trigger a reduction in the barriers to BIM adoption.

	BIM motivation strategies that are required to trigger a reduction in the barriers to BIM adoption on construction projects	Mean score
1	Publication of BIM success stories	3.77
2	Need to improve organizational performance and efficiency in long terms	3.74
3	Availability of information on BIM concepts	3.73
4	Need to improve competitiveness in project bidding	3.71
5	BIM adoption among peer firms	3.70
6	Need to improve organizational performance and efficiency in short terms	3.70
7	BIM adoption as a way of encouraging development in the construction industry	3.68
8	Availability of BIM proficient graduates	3.67
9	Availability of national BIM standards	3.67
10	Advertisement and programs for BIM awareness	3.66
11	Need to be seen as being up-to-date and technologically sophisticated	3.66
12	Need to adapt to global best practices and trends	3.66
13	The possibility of getting high-value clients	3.65
14	Government-sponsored BIM-based pilot projects	3.64
15	Availability of guidelines on BIM protocols	3.64
16	Prevalent BIM adoption among the top and successful firms	3.63
17	Report of BIM usage on a widely acclaimed successful projects	3.63
18	BIM adoption by rival firms	3.61
19	Availability of legalities and copyright ownership of BIM	3.60
20	Marketing of BIM as professional services	3.60
21	Advocacy and campaign for BIM	3.57
22	Availability of fund to assist small and medium firms to adopt BIM	3.56
23	Availability of guidelines on BIM roles and responsibilities (BIM supply chain)	3.56
24	BIM adoption as part of project team requirement	3.55
25	Need to be socially acceptable to the clients	3.55
26	BIM adoption as part of clients' requirement	3.51
27	BIM adoption as conformity to regulations and rules	3.47
28	BIM adoption as a marketing strategy	3.47
29	BIM adoption as a requirement in the company's supply chain network	3.47
30	Mandatory requirement of BIM for building permit application	3.46
31	BIM adoption as a corporate social responsibility strategy	3.39
32	Mandatory requirement of BIM in the contractor selection process	3.38

Table 5.21: MIS of responses on BIM capacity development strategies that are required to trigger a reduction in the barriers to BIM adoption.

	BIM capacity development strategies that are required to trigger a reduction in the barriers to BIM adoption on construction projects	Mean score
1	BIM technology educational programme in colleges, technical and vocational institutes	3.79
2	On-the-job BIM training for the employees	3.78
3	BIM education at the undergraduate programme at the university	3.78
4	BIM application and management programme at post-graduate level in the university	3.78
5	BIM workshops	3.77
6	BIM seminars	3.74
7	Self-initiated BIM training	3.69
8	Corporate BIM training partners	3.65
9	BIM research and development	3.64
10	Peer-group-influenced BIM training	3.62
11	Pre-labour market-influenced BIM training	3.61
12	BIM training during Industrial Training/Internship	3.61
13	2D and 3D CAD education in the secondary school	3.60
14	Upbringing by BIM proficient parents	3.35

Table 5.22: MIS of responses on BIM utilisation strategies that are required to trigger a reduction in the barriers to BIM adoption.

	BIM utilisation strategies that are required to trigger a reduction in the barriers to BIM adoption on construction projects	Mean score
1	Assessing the performance of BIM adoption on construction projects	3.85
2	Determining the appropriate import and export file format for different types of project complexities	3.76
3	Developing digital object identifiers for building materials manufacturers	3.75
4	Determining the required BIM capacity of the construction project supply chain members based on the types of project	3.74
5	Sharing BIM cost and benefits between the client and the supply chain members	3.72
6	Determining the appropriate number of professionals to form the construction project supply chain network	3.72
7	Developing digital object identifiers for supply chain	3.71
8	Determining the appropriate BIM maturity levels [3D, 4D, 5D, 6D] for different types of project complexities	3.7
9	Determining the appropriate collaborative procurement system for different types of project complexities	3.7
10	Determining the appropriate level of development of building information models for different types of project complexities	3.67
11	Determining the appropriate form of collaboration required for different types of project complexities	3.67
12	Determining the appropriate types of professionals to form the construction project supply chain network	3.64
13	Determining the appropriate intensity of collaboration required for different types of project complexities	3.61

Table 5.27: Measured variables for the barriers to preliminary BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ʐ
P1	The absence of in-house BIM competent professionals	3.55	.93	.99	.96	20.59	93.57	.97	Chi-square: 52945.640 Significance: 0.000
P2	Lack of resources to train employees	3.53	.91		.95				
P3	Unavailability of BIM competent professionals in the labor market	3.51	.93		.96				
P4	Lack of cooperation among firms in the industry	3.51	.96		.98				
P5	Lack of understanding of BIM	3.50	.93		.96				
P6	Non-communication of BIM concept by relevant industry leadership	3.50	.94		.97				
P7	Lack of cooperation among professionals in the industry	3.50	.96		.98				
P8	Lack of BIM awareness among clients	3.50	.94		.97				
P9	Lack of enforcement from industry leadership	3.48	.93		.96				
P10	Lack of awareness of BIM	3.47	.92		.96				
P11	Lack of business case for BIM adoption	3.47	.94		.97				
P12	Lack of resources to acquire BIM tools and technologies	3.44	.94		.97				
P13	Lack of enforcement from government agencies	3.41	.92		.96				
P14	Lack of interests in BIM among clients	3.40	.94		.97				
P15	Lack of clarity of professional roles in BIM	3.39	.93		.96				
P16	Satisfaction with existing work methods and process	3.34	.92		.96				
P17	Lack of trust among firms in the industry	3.31	.94		.97				
P18	Unavailability of BIM guidelines and standards	3.29	.94		.97				
P19	Clashes in professional responsibility in BIM	3.27	.90		.95				
P20	Incompatibility and interoperability of BIM software technologies	3.25	.91		.95				
P21	Lack of trust among professionals in the industry	3.22	.94		.97				
P22	Lack of policies and regulations on copyright ownership	3.21	.90		.95				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ʐ=Bartlett's test.

Table 5.28: Measured variables for the barriers to sustained BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
S1	Lack of information on BIM tools and technologies	3.47	.96	.99	.98	26.26	93.79	.97	Chi-square: 70562.95 Significance: 0.000
S2	Top management not engaging BIM consultants to facilitate BIM usage	3.47	.96		.98				
S3	Lack of understanding and identification of BIM tools and technologies	3.43	.95		.97				
S4	Failure to understand how BIM adoption will change business processes	3.43	.91		.95				
S5	Lack of coordination(BIM champion or steering committee) across different supply chain members	3.42	.95		.97				
S6	Unavailability of BIM infrastructures in the organization	3.38	.93		.96				
S7	The rigidity of organizational structures	3.38	.95		.97				
S8	Lack of capacity to meet BIM implementation demands	3.37	.95		.97				
S9	Unavailability of BIM implementation experts (BIM consultants)	3.36	.93		.96				
S10	Lack of collaborative teamwork culture in the organization	3.33	.94		.96				
S11	Lack of a clear strategy for BIM usage on projects	3.33	.93		.96				
S12	Lack of framework for BIM platforms selection	3.32	.94		.97				
S13	Lack of coordination(BIM champion or steering committee) across different functional areas	3.31	.94		.97				
S14	Lack of patience and understanding of the structural changes needed	3.29	.94		.97				
S15	Skepticism about the benefits of BIM adoption	3.28	.91		.95				
S16	Employees' unwillingness to accept changes	3.26	.92		.96				
S17	The perspective of BIM as just a technology	3.26	.93		.96				
S18	Lack of awareness of the competitive situation of the firms	3.25	.93		.96				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.28: Measured variables for the barriers to sustained BIM adoption (cont'd)

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ʐ
S19	Lack of patience and understanding of the cultural changes needed	3.23	.94	.99	.96	26.26	93.79	.97	Chi-square: 70562.95 Significance: 0.000
S20	The inadequacy of BIM to support the existing organizational work	3.21	.92		.96				
S21	The inadequacy of BIM to support the existing business process	3.21	.93		.96				
S22	The inadequacy of BIM to meet project expectations	3.19	.93		.96				
S23	Conflict of interests between BIM adoption and organizational vision and objectives	3.16	.91		.95				
S24	Fear of loss of competitive advantage	3.15	.94		.97				
S25	Lack of motivation for workers	3.15	.92		.96				
S26	Inappropriate change management processes	3.10	.92		.96				
S27	The inadequacy of BIM to meet organizational expectations	3.06	.92		.96				
S28	The inadequacy of BIM to meet clients' expectations	3.04	.93		.96				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ʐ=Bartlett's test.

Table 5.29a: Measured variables for motivation strategies that are employed to trigger a reduction in the barriers to BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
Y11	Need to improve organizational performance and efficiency in long terms	3.82	.93	.99	.96	27.04	93.25	.96	Chi-square: 74840.78 Significance: 0.000
Y12	Need to improve organizational performance and efficiency in short terms	3.79	.89		.94				
Y13	Need to improve competitiveness in project bidding	3.76	.90		.95				
Y14	Need to adapt to global trends	3.73	.94		.97				
Y15	Need to adapt to global best practices	3.72	.95		.97				
Y16	The possibility of getting high-value clients	3.60	.94		.97				
Y17	Prevalent BIM adoption among the top and successful firms	3.56	.94		.97				
Y18	BIM adoption as a way of supporting development in the construction industry	3.55	.94		.97				
Y19	Report of BIM usage on a widely acclaimed successful projects	3.55	.92		.96				
Y110	Need to be seen as being up-to-date and technologically sophisticated	3.55	.92		.96				
Y111	BIM adoption as part of project team requirement	3.54	.91		.95				
Y112	BIM adoption among peer firms	3.52	.93		.96				
Y113	Availability of information on BIM concepts	3.49	.95		.97				
Y114	BIM adoption as conformity to regulations and rules	3.48	.89		.94				
Y115	BIM adoption as part of clients' requirement	3.46	.90		.94				
Y116	Need to be socially acceptable to the clients	3.45	.94		.97				
Y117	Publication of BIM success stories	3.41	.90		.95				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.29a: Measured variables for motivation strategies that are employed to trigger a reduction in the barriers to BIM adoption (cont'd).

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
Y118	BIM adoption by rival firms	3.37	.89	.99	.94	27.04	93.25	.96	Chi-square: 74840.78 Significance : 0.000
Y119	BIM adoption as a requirement in the company's supply chain network	3.36	.94		.97				
Y120	Availability of guidelines on BIM roles and responsibilities (BIM supply chain)	3.35	.95		.97				
Y121	BIM adoption as a marketing strategy	3.32	.94		.97				
Y122	BIM adoption as a corporate social responsibility strategy	3.31	.90		.95				
Y123	Advertisement and programs for BIM awareness	3.31	.92		.96				
Y124	Availability of legalities and copyright ownership of BIM	3.30	.94		.97				
Y125	Marketing of BIM as professional services	3.30	.93		.96				
Y126	Availability of guidelines on BIM protocols	3.25	.95		.97				
Y127	Advocacy and campaign for BIM	3.25	.95		.97				
Y128	Availability of BIM proficient graduates	3.25	.92		.95				
Y129	Government-sponsored BIM-based pilot projects	3.22	.93		.96				
Y130	Availability of fund to assist small and medium firms to adopt BIM	3.22	.93		.96				
Y131	Availability of national BIM standards	3.21	.93		.96				
Y132	Mandatory requirement of BIM for building permit application	3.16	.92		.96				
Y133	Mandatory requirement of BIM in the contractor selection process	3.09	.94		.97				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.29b: Measured variables for top management commitment strategies that are employed to trigger a reduction in the barriers to BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ʐ
Y21	Coordination of the BIM process in the organization	3.54	.87	.99	.93	33.82	93.95	.97	Chi-square: 96950.100 Significance: 0.000
Y22	Educating staff on the potentials of BIM	3.54	.94		.97				
Y23	Introduction of collaborative teamwork culture in the organization	3.53	.94		.97				
Y24	Allowing staff members to participate in the work process redesign process	3.53	.91		.95				
Y25	Development of new values for staff members	3.49	.94		.97				
Y26	Effective communication between stakeholders	3.47	.94		.97				
Y27	Incorporation of BIM into the vision of the organization	3.44	.96		.98				
Y28	Development of communication styles	3.42	.95		.97				
Y29	Development of new management processes	3.41	.96		.98				
Y210	Ensuring effective use of BIM tools	3.41	.94		.97				
Y211	Provision of infrastructures (BIM environment) for BIM	3.39	.96		.98				
Y212	Adaptation of BIM concepts to the organizational culture	3.34	.95		.97				
Y213	Introduction of new roles and job titles	3.34	.94		.97				
Y214	Creation of a new organizational structure	3.34	.95		.97				
Y215	Adherence to the BIM process	3.34	.92		.96				
Y216	Exploration of the usage of BIM on pilot projects	3.33	.95		.97				
Y217	Provision of technical support services in the organization	3.33	.95		.97				
Y218	Appointing BIM champions	3.33	.95		.97				
Y219	An increment in the staff development budget	3.32	.92		.96				
Y220	Provision of in-house BIM training	3.31	.93		.96				
Y221	Documentation of the proceedings of BIM-based projects	3.30	.96		.98				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ʐ=Bartlett's test.

Table 5.29b: Measured variables for top management commitment strategies that are employed to trigger a reduction in the barriers to BIM adoption (cont'd).

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
Y222	Adherence to BIM protocols	3.30	.94	.99	.97	33.82	93.95	.97	Chi-square: 96950.100 Significance: 0.000
Y223	Development of performance measures for BIM adoption	3.29	.95		.97				
Y224	Identification of business opportunities in BIM adoption	3.26	.94		.97				
Y225	Facilitate solutions to projects contingencies [incidents and challenges] brought about by BIM adoption	3.25	.97		.98				
Y226	Appointing BIM managers	3.25	.90		.95				
Y227	Stimulating BIM adoption with investments	3.24	.95		.97				
Y228	Anticipating and planning for BIM adoption risk management	3.24	.95		.97				
Y229	BIM consultants engagement	3.23	.95		.97				
Y230	Facilitate solutions to clients contingencies brought about by BIM adoption	3.22	.96		.98				
Y231	Facilitate solutions to organizations contingencies brought about BIM adoption	3.19	.97		.98				
Y232	Provision of incentives for BIM capacity development	3.03	.86		.92				
Y233	Revision of wage structure	2.99	.92		.96				
Y234	Provision of incentives [bonus and allowance] for BIM usage	2.95	.90		.95				
Y235	Revision of the reward system	2.93	.92		.96				
Y236	Sanctions [querries and demotion] for resistance towards BIM usage	2.87	.87		.93				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.29c: Measured variables for capacity development strategies that are employed to trigger a reduction in the barriers to BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
Y31	Self-initiated BIM training	3.56	.93	.99	.96	13.29	94.90	.96	Chi-square: 33678.52 Significance: 0.000
Y32	BIM workshops	3.55	.95		.97				
Y33	BIM seminars	3.53	.94		.97				
Y34	On-the-job BIM training for the employees	3.53	.93		.96				
Y35	BIM technology educational program in colleges, technical and vocational institutes	3.50	.96		.98				
Y36	BIM application and management program at post-graduate level in the university	3.49	.93		.96				
Y37	BIM education at the undergraduate programme at the university	3.44	.96		.98				
Y38	Corporate BIM training partners	3.42	.97		.98				
Y39	BIM training during Industrial Training/Internship	3.40	.96		.98				
Y310	Peer-group-influenced BIM training	3.39	.96		.98				
Y311	BIM research and development	3.28	.93		.96				
Y312	2D and 3D CAD education in the secondary school	3.22	.95		.97				
Y313	Pre-labour market-influenced BIM training	3.20	.93		.96				
Y314	Upbringing by BIM proficient parents	3.16	.93		.96				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.29d: Measured variables for BIM utilisation strategies that are employed to trigger a reduction in the barriers to BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
Y41	Determining the appropriate form of collaboration required for the project	3.60	.96	.99	.98	13.30	95.05	.96	Chi-square: 35040.29 Significance: 0.000
Y42	Determining the appropriate import and export file format for the project	3.60	.96		.98				
Y43	Determining the appropriate intensity of collaboration required for the project	3.59	.96		.98				
Y44	Determining the appropriate BIM maturity levels [3D, 4D, 5D, 6D] for the project	3.56	.91		.95				
Y45	Determining the appropriate BIM platform for the project	3.56	.95		.97				
Y46	Determining the appropriate collaborative procurement system	3.49	.95		.97				
Y47	Assessing the performance of BIM adoption on the project	3.47	.97		.98				
Y48	Developing digital object identifiers for building materials manufacturers	3.46	.94		.97				
Y49	Determining the appropriate level of development of building information models	3.45	.97		.98				
Y410	Developing digital object identifiers for supply chain	3.40	.91		.95				
Y411	Determining the appropriate types of professionals to form the construction project supply chain network	3.38	.95		.97				
Y412	Determining the appropriate number of professionals to form the construction project supply chain network	3.37	.95		.97				
Y413	Determining the required BIM capacity of the construction project supply chain members based on the project type	3.36	.96		.98				
Y414	Sharing BIM cost and benefits between the client and the supply chain members	3.26	.90		.95				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.30: Measured variables for the indicators of a reduction in barriers to BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
M1	Acquisition of resources for BIM training of employees	3.48	.95	.99	.97	30.33	94.79	.96	Chi-square: 92346.89 Significance: 0.000
M2	Acquisition of BIM software technologies	3.47	.95		.97				
M3	BIM-induced changes in construction business process	3.45	.96		.98				
M4	Availability of BIM infrastructures in the organizations	3.42	.95		.97				
M5	Availability of policies and regulations on copyright ownership	3.41	.93		.96				
M6	Employees' readiness to accept changes	3.41	.97		.98				
M7	Availability of information on the selection of BIM software technologies for projects	3.40	.92		.96				
M8	Application of BIM tools to projects	3.40	.95		.97				
M9	Acceptance of BIM as a construction management process	3.39	.95		.97				
M10	Availability of motivation for workers towards BIM adoption	3.38	.96		.98				
M11	Evidence of collaborative teamwork culture in the organizations	3.37	.93		.96				
M12	Acceptance of BIM competency as a competitive advantage	3.36	.93		.96				
M13	Understanding of roles in BIM adoption by CPSC stakeholder	3.36	.96		.98				
M14	Regular organization of BIM workshop by regular industry leadership	3.35	.94		.97				
M15	Availability of national BIM guidelines	3.34	.94		.97				
M16	Aligning project expectations with BIM potentials	3.34	.93		.96				
M17	Acceptance of BIM as a work process	3.34	.94		.97				
M18	Availability of interoperable BIM software technologies	3.33	.93		.96				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.30: Measured variables for the indicators of a reduction in barriers to BIM adoption (cont'd).

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
M19	Aligning organizational vision and objectives with BIM adoption	3.33	.96	.99	.98	30.33	94.79	.96	Chi-square: 92346.89 Significance: 0.000
M20	Awareness of BIM by Construction Project Supply Chain (CPSC) stakeholders	3.31	.89		.94				
M21	Availability of national BIM standards	3.31	.94		.97				
M22	Awareness of BIM by clients	3.29	.93		.96				
M23	Understanding of BIM concepts by CPSC stakeholders	3.28	.93		.96				
M24	Aligning organizational culture with BIM adoption requirements	3.28	.96		.98				
M25	Understanding of responsibilities in BIM adoption by CPSC stakeholder	3.28	.96		.98				
M26	Availability of BIM competent professionals in the labor market	3.25	.96		.98				
M27	Appointment of BIM champion or steering committee	3.25	.95		.97				
M28	Aligning organizational structures with BIM adoption requirements	3.25	.97		.98				
M29	Availability of in-house BIM competent professionals	3.23	.93		.96				
M30	Enforcement of BIM adoption on projects by private clients	3.23	.94		.97				
M31	Enforcement of BIM adoption on projects by public clients	3.22	.92		.96				
M32	Enforcement of BIM adoption on public-private projects	3.22	.95		.97				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.31a: Measured variables for criteria for assessing BIM performance on BBCPs.

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
K11	Improved work quality	3.54	.79	.98	.85	25.84	61.52	.94	Chi-square: 7164.36 Significance: 0.000
K12	Improved client satisfaction	3.53	.80		.83				
K13	Fast project delivery	3.49	.75		.81				
K14	Effective communication	3.46	.78		.80				
K15	Broaden the understanding of project needs	3.44	.81		.85				
K16	Increased knowledge transfer	3.42	.76		.81				
K17	Improved cooperation	3.39	.71		.76				
K18	Trust and commitment	3.38	.79		.87				
K19	Improved professional attitude	3.37	.73		.74				
K110	Increased information exchange	3.34	.78		.79				
K111	Improved cost control and management	3.34	.80		.82				
K112	Improved information quality	3.32	.72		.73				
K113	Improved safety management	3.32	.78		.77				
K114	A valued and quick decision-making process	3.32	.78		.84				
K115	Increased labor productivity	3.31	.71		.81				
K116	Coordinated decision-making	3.30	.70		.82				
K117	Allows design review	3.30	.84		.75				
K118	Improved client participation	3.30	.75		.75				
K119	Improved schedule management	3.29	.86		.84				
K120	Improved team culture	3.22	.72		.76				
K121	Enhanced service quality	3.22	.76		.80				
K122	Competitive advantage	3.21	.76		.75				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.31a: Measured variables for criteria for assessing BIM performance on BBCPs (cont'd)

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
K123	Provide time database	3.19	.77	.98	.75	25.84	61.52	.94	Chi-square: 7164.36 Significance: 0.000
K124	Eliminate waste	3.18	.77		.77				
K125	Improved profit margin	3.18	.77		.75				
K126	Fewer request for information	3.17	.73		.75				
K127	Reduced contractual claims	3.15	.77		.77				
K128	Allows clash detection	3.14	.81		.76				
K129	Intelligent documentation	3.12	.77		.78				
K130	Improved operation and maintenance of facilities	3.09	.71		.81				
K131	Improved marketing	3.09	.72		.74				
K132	Fewer change order	3.07	.75		.73				
K133	Easy retrieval of building data	3.06	.74		.83				
K134	Supply chain integration	3.04	.79		.78				
K135	Integrated and interactive database	3.04	.72		.76				
K136	Performance simulation	3.02	.71		.79				
K137	Enables e-procurement of materials and components	2.98	.76		.72				
K138	Effective supply chain management	2.98	.77		.74				
K139	Improved energy performance	2.93	.71		.72				
K140	Improved prefabrication	2.86	.72		.76				
K141	Enhanced data interoperability	2.85	.78		.74				
K142	Improved deconstruction management	2.78	.73		.72				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.31b: Measured variables for BIM capacity utilised on BBCPs.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
K21	Competence in 3D CAD tools and software technologies	2.74	.76	.85	.78	3.15	62.91	.77	Chi-square: 448.29 Significance: 0.000
K22	Information integration skills	2.70	.87		.75				
K23	Multi-disciplinary collaboration skills	2.63	.78		.71				
K24	Competence in BIM tools and software technologies	2.62	.73		.73				
K25	Information exchange skills	2.59	.80		.65				
X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.									

Table 5.31c: Measured variables for BIM tools employed on BBCPs.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
K31	Budget simulation	3.18	.79	.97	.73	16.51	56.93	.93	Chi-square: 4183.45 Significance: 0.000
K32	Construction sequencing	3.15	.76		.72				
K33	Visualization/rendering,	3.11	.70		.77				
K34	Life-cycle costing	2.94	.71		.74				
K35	Clash detections and model checking	2.90	.70		.79				
K36	Construction simulation	2.89	.75		.75				
K37	As-built BIM model	2.88	.76		.72				
K38	Virtual mock-up models	2.87	.72		.72				
K39	Walkthroughs	2.83	.76		.73				
K310	Automatic cost data extraction	2.82	.70		.76				
K311	Automatic quantification	2.82	.72		.72				
X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.									

Table 5.31c: Measured variables for BIM tools employed on BBCPs (cont'd)

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
K312	Optimization	2.78	.72	.97	.79	16.51	56.93	.93	Chi-square: 4183.45 Significance: 0.000
K313	3D-object based models	2.77	.77		.72				
K314	Fabrication models [digital fabrication]	2.72	.73		.78				
K315	Automatic cost data update	2.71	.71		.81				
K316	Life cycle analysis	2.66	.71		.77				
K317	BIM maintenance plans and technical support	2.60	.73		.85				
K318	Intelligent asset management	2.58	.70		.83				
K319	BIM embedded operation and maintenance manuals	2.55	.70		.83				
K320	Detailed energy analysis	2.54	.75		.79				
K321	Sustainable element tracking	2.53	.78		.87				
K322	4D scheduling	2.51	.55		.73				
K323	Conceptual energy analysis	2.51	.73		.81				
K324	Forensic analysis	2.39	.70		.77				
K325	LEED tracking	2.38	.76		.82				
K326	Ground penetration radar conversions	2.34	.75		.78				
K327	Laser scanning	2.27	.70		.73				
K328	Animations	2.26	.77		.74				
K329	CoBie data population and extraction	2.23	.83		.85				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.31d: Measured variables for types of building information models developed for BBCPs.

Code	**Variables**	**χ**	**γ**	**ϕ**	**Φ**	**µ**	**ß**	**ƛ**	**ʐ**
K41	Construction plan and schedule	3.55	.82	.96	.77	11.10	58.42	.93	Chi-square: 2816.51 Significance: 0.000
K42	Construction health and safety information model	3.41	.79		.79				
K43	Cost and quantities of information model	3.39	.77		.75				
K44	Structural information model	3.38	.75		.72				
K45	Construction system information model	3.36	.83		.75				
K46	Architectural information model	3.33	.73		.76				
K47	Electrical services information model	3.20	.77		.79				
K48	Structural steelwork fabrication information model	3.19	.74		.76				
K49	A mechanical services information model	3.03	.79		.77				
K410	Lighting analysis information model	3.00	.71		.77				
K411	Maintenance and operation schedule	2.93	.77		.75				
K412	Sustainability analysis information model	2.90	.71		.81				
K413	Mechanical system ductwork fabrication information model	2.89	.71		.82				
K414	Energy analysis information model	2.87	.72		.81				
K415	Pre-cast panels fabrication information model	2.77	.78		.78				
K416	Glazing system fabrication information model	2.77	.76		.85				
K417	Curtain walling fabrication information model	2.66	.82		.78				
K418	Crane assignment information model	2.53	.70		.75				
K419	Rain screens fabrication information model	2.51	.83		.77				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ʐ=Bartlett's test.

Table 5.31e: Measured variables for the level of clarity of objects that were used to develop building information models for BBCPs.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
K51	G3 – Rendered (description, dimension, manufacturer's details, model's details & image)	3.00	.82	.91	.90	3.1 4	78.59	.79	Chi-square: 468.59 Significance: 0.000
K52	G2 – Defined (description, dimension, manufacturer's details & model's details)	2.94	.81		.90				
K53	G1 – Concept (description & dimension only)	2.78	.80		.89				
K54	G0 – Schematic (description only)	2.64	.70		.84				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.32a: Measured variables for trust-based relationships among the BIM-SCM.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
Z11	Problem-solving ability	3.85	.79	.97	.79	16.65	55.49	.91	Chi-square: 3116.15 Significance: 0.000
Z12	Competence of personnel	3.84	.82		.73				
Z13	Competence of organizations	3.69	.82		.71				
Z14	Consistent integrity	3.66	.78		.78				
Z15	Openness in sharing information	3.65	.72		.71				
Z16	Mutual exchange of ideas	3.59	.77		.80				
Z17	Honesty and mutual commitment	3.55	.79		.74				
Z18	Freedom to state opinions and perspectives	3.51	.72		.78				
Z19	Cross-functional cooperation	3.50	.72		.73				
Z110	Display of confidence for each other by supply chain members	3.50	.78		.80				
Z111	Support for innovation and learning	3.48	.81		.82				
Z112	Shared interests and project expectations	3.47	.74		.75				
Z113	Conflict resolution	3.46	.70		.78				
Z114	Inter-personal relationship	3.43	.83		.86				
Z115	Inter-organizational relationship	3.43	.77		.83				
Z116	Social interaction between supply chain members	3.40	.74		.74				
Z117	Risk sharing	3.40	.78		.71				
Z118	Mutual rewards and benefits	3.40	.74		.80				
Z119	Work interaction between supply chain members	3.39	.73		.79				
Z120	The emotional interaction between the project team	3.35	.79		.74				
Z121	The absence of competing interests	3.29	.76		.77				
Z122	Absence of tribalism	3.28	.85		.76				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.32a: Measured variables for trust-based relationships among the BIM-SCM (cont'd)

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
Z123	The absence of professional stereotypes	3.27	.75	.97	.71	16.65	55.49	.91	Chi-square: 3116.15 Significance: 0.000
Z124	Absence of racism	3.26	.81		.70				
Z125	Compensating for each other's weaknesses	3.22	.73		.80				
Z126	Persistence of relationship after projects	3.21	.76		.77				
Z127	Non-misuse of information by supply chain members	3.20	.75		.71				
Z128	The absence of defensive behavior	3.18	.73		.76				
Z129	Lack of confrontation and adversarial relationship	3.12	.78		.71				
Z130	Exploiting each other's strengths	3.11	.73		.77				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.32b: Measured variables for information sharing and exchange among the BIM-SCM.

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
Z21	Information shared is credible	3.73	.94	.99	.97	19.59	99.32	.97	Chi-square: 48837.07 Significance: 0.000
Z22	Clarity of information	3.67	.95		.97				
Z23	The high quality of information	3.66	.94		.97				
Z24	Information shared is accurate	3.60	.92		.96				
Z25	Usage of collaborative electronic media for information sharing	3.53	.92		.96				
Z26	Timely sharing of information	3.53	.94		.97				
Z27	Adequacy of information	3.47	.95		.97				
Z28	Enhanced interpersonal sharing and exchange of information	3.46	.91		.95				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.32b: Measured variables for information sharing and exchange among the BIM-SCM (cont'd).

Code	**Variables**	**χ**	**γ**	**ϕ**	**Φ**	**μ**	**ß**	**ƛ**	**ʐ**
Z29	Selection of information sharing channels	3.42	.94	.99	.97	19.59	99.32	.97	Chi-square: 48837.07 Significance: 0.000
Z210	Usage of information exchange format for integrating project information	3.39	.94		.97				
Z211	Non-withholding of information	3.35	.91		.95				
Z212	Cross-boundary information sharing/enhanced inter-organizational sharing and exchange of information	3.34	.93		.96				
Z213	Usage of information sharing protocols	3.32	.93		.96				
Z214	Usage of consistent data structures and definitions	3.28	.93		.96				
Z215	Creation of homogeneous or single project information database	3.27	.94		.97				
Z216	The absence of conflicting information	3.22	.92		.96				
Z217	Non-distortion or manipulation of information	3.20	.91		.95				
Z218	Linking and integration of project information/ data federation	3.18	.91		.95				
Z219	Flawless information exchange	3.15	.91		.95				
Z220	File-based data interoperability	3.14	.94		.96				
Z221	Server-based data interoperability	3.09	.92		.96				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ʐ=Bartlett's test.

Table 5.32c: Measured variables for network communication among the BIM-SCM.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ʐ
Z31	Documentation of communication	3.78	.96	.99	.98	19.86	94.55	.97	Chi-square: 53299.77 Significance: 0.000
Z32	Formation of open and formal communication channels	3.76	.90		.95				
Z33	Communication across the stages in the project life-cycle	3.70	.97		.98				
Z34	Regular interpersonal communication	3.66	.94		.97				
Z35	Adoption of common electronic communication platforms	3.64	.93		.96				
Z36	Establishment of a secured line of communication	3.61	.93		.96				
Z37	Usage of communication protocols	3.61	.95		.97				
Z38	Regular team communication	3.58	.93		.96				
Z39	Real-time communication	3.55	.96		.98				
Z310	Feedback communication	3.55	.94		.97				
Z311	Regular inter-group communication	3.53	.95		.97				
Z312	Timely communication	3.51	.94		.97				
Z313	Flexibility of formalities	3.50	.94		.97				
Z314	Regular inter-organizational communication	3.50	.95		.97				
Z315	Positive corporate communication	3.49	.95		.97				
Z316	The multi-directional flow of information	3.48	.96		.98				
Z317	Adoption of joint problem-solving techniques	3.46	.95		.97				
Z318	Reciprocal flow of information	3.39	.95		.97				
Z319	Problem-solving structured e-meeting	3.39	.93		.96				
Z320	Agenda-driven structured e-meeting	3.27	.92		.95				
Z321	Open-ending structured e-meeting	3.24	.91		.95				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ʐ=Bartlett's test.

Table 5.32d: Measured variables for knowledge sharing and transfer among the BIM-SCM.

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
Z41	Valued decision-making	3.75	.75	.98	.83	17.28	63.99	.92	Chi-square: 3141.184 Significance: 0.000
Z42	Understanding of information	3.72	.76		.72				
Z43	Quick decision-making	3.70	.85		.83				
Z44	The high quality of information	3.65	.78		.78				
Z45	Collective decision-making	3.63	.76		.85				
Z46	Willingness to share resources	3.60	.76		.76				
Z47	Inter-personal knowledge sharing	3.60	.80		.81				
Z48	Inter-team knowledge sharing	3.57	.70		.80				
Z49	Usage of collaborative electronic media for knowledge sharing	3.52	.74		.72				
Z410	Identification of clashes and omission in information models	3.49	.77		.78				
Z411	Review of projects after completion	3.48	.79		.83				
Z412	Sharing of knowledge on best practices among the supply chain members	3.48	.78		.74				
Z413	Inter-professional knowledge sharing	3.46	.82		.83				
Z414	Database creation and management	3.45	.79		.84				
Z415	Inter-group knowledge sharing	3.45	.75		.79				
Z416	Knowledge documentation in the form of the project proceeding	3.45	.78		.78				
Z417	Sharing of collaborative experiences among the supply chain members	3.42	.78		.77				
Z418	Extraction of measurement information from the information models	3.41	.70		.82				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.32d: Measured variables for knowledge sharing and transfer among the BIM-SCM (cont'd)

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ζ
Z419	Inter-organizational knowledge sharing	3.40	.72	.98	.84	17.28	63.99	.92	Chi-square: 3141.184 Significance: 0.000
Z420	Sharing of project lesson learned among supply chain members	3.40	.77		.82				
Z421	Extraction of cost information from information models	3.34	.82		.78				
Z422	Extraction of installation information from the information models	3.30	.79		.80				
Z423	Sharing of project reviews among supply chain members	3.29	.74		.80				
Z424	Extraction of manufacturer's details from the information models	3.29	.75		.80				
Z425	Extraction of fabrication information from the information models	3.28	.74		.73				
Z426	Parametric and object-oriented design of information models	3.27	.71		.80				
Z427	Extraction of tendering/bidding information from the information models	3.26	.79		.79				
Z428	Sharing of insights among the supply chain members	3.21	.76		.72				
Z429	Extraction of operation and maintenance information from the information models	3.20	.80		.79				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ζ=Bartlett's test.

Table 5.33a: Measured variables for the quality of dedication and commitment that are required to trigger a reduction in the barriers to BIM adoption.

Code	**Variables**	**χ**	**γ**	**ϕ**	**Φ**	**μ**	**ß**	**ƛ**	**ɀ**
X11	Educating staff on the potentials of BIM	3.77	.96	.99	.98	34.22	95.06	.96	Chi-square: 107437.80 Significance: 0.000
X12	Provision of in-house BIM training	3.74	.93		.96				
X13	Adherence to BIM protocols	3.72	.93		.96				
X14	Exploration of the usage of BIM on pilot projects	3.71	.96		.98				
X15	Provision of technical support services in the organization	3.71	.97		.98				
X16	Development of management processes	3.69	.96		.98				
X17	Provision of infrastructures (BIM environment) for BIM	3.67	.96		.98				
X18	Effective communication between stakeholders	3.67	.96		.98				
X19	Allowing staff members to participate in the work process redesign process	3.67	.97		.98				
X110	Development of communication styles	3.67	.96		.98				
X111	Introduction of collaborative teamwork culture in the organization	3.66	.97		.98				
X112	Adherence to the BIM process	3.66	.93		.96				
X113	Documentation of the proceedings of BIM-based projects	3.63	.94		.97				
X114	Creation of a new organizational structure	3.63	.95		.97				
X115	Adaptation of BIM concepts to the organizational culture	3.61	.94		.97				
X116	Ensuring effective use of BIM tools	3.61	.94		.97				
X117	Development of new values	3.60	.93		.96				
X118	Incorporation of BIM into the vision of the organization	3.59	.95		.97				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.33a: Measured variables for the quality of dedication and commitment that are required to trigger a reduction in the barriers BIM adoption (cont'd)

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
X119	Anticipating and planning for BIM adoption risk management	3.59	.96	.99	.98	34.22	95.06	.96	Chi-square: 107437.80 Significance: 0.000
X120	Coordination of the BIM process in the organization	3.57	.91		.95				
X121	An increment in the staff development budget	3.57	.96		.98				
X122	Identification of business opportunities in BIM adoption	3.57	.96		.98				
X123	Facilitating solutions to organizations contingencies of BIM adoption	3.56	.94		.97				
X124	Introduction of new roles and job titles	3.55	.96		.98				
X125	Appointing BIM champions	3.55	.96		.98				
X126	Appointing BIM managers	3.54	.96		.98				
X127	Development of performance measures for BIM adoption	3.52	.96		.98				
X128	Facilitating solutions to projects contingencies of BIM adoption	3.49	.97		.98				
X129	Stimulating BIM adoption with investments	3.49	.94		.97				
X130	Facilitating solutions to clients contingencies of BIM adoption	3.48	.95		.97				
X131	BIM consultants engagement	3.42	.96		.98				
X132	Revision of wage structure	3.40	.94		.97				
X133	Provision of incentives [bonus and allowance] for BIM usage	3.35	.89		.94				
X134	Revision of the reward system	3.35	.92		.96				
X135	Provision of incentives for BIM capacity development	3.34	.91		.95				
X136	Sanctions [queries and demotion] for resistance towards BIM usage	3.22	.90		.95				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.33b: Measured variables for the motivations that are required to trigger a reduction in the barriers to BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
X21	Publication of BIM success stories	3.77	.96	.99	.98	30.52	95.36	.96	Chi-square: 93036.19 Significance: 0.000
X22	Need to improve organizational performance and efficiency in long terms	3.74	.95		.97				
X23	Availability of information on BIM concepts	3.73	.96		.98				
X24	Need to improve competitiveness in project bidding	3.71	.95		.97				
X25	BIM adoption among peer firms	3.70	.93		.96				
X26	Need to improve organizational performance and efficiency in short terms	3.70	.96		.98				
X27	BIM adoption as a way of encouraging development in the construction industry	3.68	.96		.98				
X28	Availability of BIM proficient graduates	3.67	.96		.98				
X29	Availability of national BIM standards	3.67	.96		.98				
X210	Advertisement and programs for BIM awareness	3.66	.96		.98				
X211	Need to be seen as being up-to-date and technologically sophisticated	3.66	.95		.97				
X212	Need to adapt to global best practices and trends	3.66	.96		.98				
X213	The possibility of getting high-value clients	3.65	.94		.97				
X214	Government-sponsored BIM-based pilot projects	3.64	.94		.97				
X215	Availability of guidelines on BIM protocols	3.64	.97		.98				
X216	Prevalent BIM adoption among the top and successful firms	3.63	.91		.95				
X217	Report of BIM usage on a widely acclaimed successful projects	3.63	.96		.98				
X218	BIM adoption by rival firms	3.61	.93		.96				
X219	Availability of legalities and copyright ownership of BIM	3.60	.97		.98				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.33b: Measured variables for the motivations that are required to trigger a reduction in the barriers to BIM adoption (cont'd).

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ƺ
X220	Marketing of BIM as professional services	3.6	.96	.99	.98	30.52	95.36	.96	Chi-square: 93036.19 Significance: 0.000
X221	Advocacy and campaign for BIM	3.57	.97		.98				
X222	Availability of fund to assist small and medium firms to adopt BIM	3.56	.94		.97				
X223	Availability of guidelines on BIM roles and responsibilities (BIM supply chain)	3.56	.96		.98				
X224	BIM adoption as part of project team requirement	3.55	.94		.96				
X225	Need to be socially acceptable to the clients	3.55	.96		.98				
X226	BIM adoption as part of clients' requirement	3.51	.95		.97				
X227	BIM adoption as conformity to regulations and rules	3.47	.95		.97				
X228	BIM adoption as a marketing strategy	3.47	.93		.96				
X229	BIM adoption as a requirement in the company's supply chain network	3.47	.94		.97				
X230	Mandatory requirement of BIM for building permit application	3.46	.96		.98				
X231	BIM adoption as a corporate social responsibility strategy	3.39	.93		.96				
X232	Mandatory requirement of BIM in the contractor selection process	3.38	.91		.95				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ƺ=Bartlett's test.

Table 5.33c: Measured variables for the BIM capacity development strategies that are required to trigger a reduction in the barriers to BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	µ	ß	ƛ	ɀ
X31	BIM technology educational programme in colleges, technical and vocational institutes	3.79	.97	.99	.98	13.49	96.38	.94	Chi-square: 39085.51 Significance: 0.000
X32	On-the-job BIM training for the employees	3.78	.98		.99				
X33	BIM education at the undergraduate programme at the university	3.78	.97		.98				
X34	BIM application and management programme at post-graduate level in the university	3.78	.98		.99				
X35	BIM workshops	3.77	.97		.98				
X36	BIM seminars	3.74	.95		.97				
X37	Self-initiated BIM training	3.69	.96		.98				
X38	Corporate BIM training partners	3.65	.97		.98				
X39	BIM research and development	3.64	.95		.97				
X310	Peer-group-influenced BIM training	3.62	.96		.98				
X311	Pre-labour market-influenced BIM training	3.61	.96		.98				
X312	BIM training during Industrial Training/Internship	3.61	.95		.97				
X313	2D and 3D CAD education in the secondary school	3.60	.96		.98				
X314	Upbringing by BIM proficient parents	3.35	.91		.95				

X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; µ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.

Table 5.33d: Measured variables for strategic BIM utilisations that are required to trigger a reduction in the barriers to BIM adoption.

Code	Variables	χ	γ	ϕ	Φ	μ	ß	ƛ	ɀ
X41	Assessing the performance of BIM adoption on construction projects	3.85	.96	.99	.98	12.53	96.36	.96	Chi-square: 35029.40 Significance: 0.000
X42	Determining the appropriate import and export file format for different types of project complexities	3.76	.95		.97				
X43	Developing digital object identifiers for building materials manufacturers	3.75	.94		.97				
X44	Determining the required BIM capacity of the construction project supply chain members based on the types of project	3.74	.96		.98				
X45	Sharing BIM cost and benefits between the client and the supply chain members	3.72	.97		.98				
X46	Determining the appropriate number of professionals to form the construction project supply chain network	3.72	.97		.98				
X47	Developing digital object identifiers for supply chain	3.71	.94		.97				
X48	Determining the appropriate BIM maturity levels [3D, 4D, 5D, 6D] for different types of project complexities	3.7	.96		.98				
X49	Determining the appropriate collaborative procurement system for different types of project complexities	3.7	.97		.98				
X410	Determining the appropriate level of development of building information models for different types of project complexities	3.67	.95		.97				
X411	Determining the appropriate form of collaboration required for different types of project complexities	3.67	.97		.98				
X412	Determining the appropriate types of professionals to form the construction project supply chain network	3.64	.97		.98				
X413	Determining the appropriate intensity of collaboration required for different types of project complexities	3.61	.97		.98				
X= mean item score; γ=factor loading; ϕ=Cronbach's alpha coefficient; Φ=correlation coefficient; μ=Eigen value; ß=% of variance explained; ƛ=Kaiser-Meyer-Olkin value; ɀ=Bartlett's test.									

APPENDIX C: DETAILED QUESTIONNAIRE

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Purpose of the questionnaire: *The purpose of this questionnaire is to examine the barriers to BIM adoption on construction projects and whether there are specific BIM implementation strategies that will bring about sustained BIM adoption practices and the best levels of integration and collaboration among the construction project supply chain stakeholders. This questionnaire survey is aimed at construction project supply chain members. Kindly answer the questions based on your experience.*

Ethical considerations: *Participation in this questionnaire survey is voluntary. Data collected in this questionnaire survey will not be shared with anyone and will be used in a combined format.*

A: RESPONDENTS & PROJECT PROFILE

*A1: RESPONDENT/COMPANY INFORMATION [**Please choose the most appropriate response from the options provided]***

i. **Company Name:**………………………………………………………………………………
ii. **Educational background of the respondents**: (a) PhD [ ] (b) Masters Degree [ ] (c) Bachelor's Degree [ ] (d) Higher Diploma [Technikon/University of Tech] [ ] (e) Certificate-Diploma with Grade 12 [ ] (f) N4-6/NTC4-6/Certificate-diploma with less than Grade 12 [ ]
iii. **Designation of respondents**: (a) Director Cadre [ ] (b) Management Cadre [ ] (c) Technical Officer [ ] (d) Others [Please Specify]……………………………..
iv. **Services provided:** (a) Consultants [ ] (b) Developer/Client [ ] (c) Construction Manager/Main contractor [ ] (d) BIM manager/Project manager [ ] (e) Subcontractor [ ] (f) Supplier [ ] (g) Specialist [ ] (h) Others………………. [Please indicate]
v. **Area of expertise**: (a) Building construction [ ] (b) Civil engineering [ ] (c) Building and Civil construction [ ] (d) Special construction/Specialist works [ ] (e) Mechanical engineering works [ ] (f) Electrical engineering works for buildings [ ] (g) Electrical engineering works for infrastructure [ ]
vi. **Location of head office:** (a) Eastern Cape [ ] (b) Western Cape [ ] (c) Free State [ ] (d) Gauteng [ ] (e) Limpopo [ ] (f) Mpumalanga [ ] (g) Northern Cape [ ] (h) North-West [ ] (i) Kwazulu Natal [ ]
vii. **Number of Employees** : (a) <50 employees [ ] (b) 51- 200 employees [ ] (c) >200 employees [ ]
viii. **Company age** : (a) Less than 5 years [ ] (b) 6 – 10 years [ ] (c) 11-15 years [ ] (d) 16 – 20 [ ] (e) 21 years and above [ ]
ix. **Region of operation** : (a) Local level [ ] (b) Provincial level [ ] (c) Regional level [ ] (d) National level [ ] (e) International level [ ]
x. **Years of Experience in Construction Industry: [e.g 15 years]**……………………………………………..

A2: PROJECT INFORMATION ***[Please identify a BIM-based project on which you are most conversant with. Use that information in answering the following questions]***

NOTE: Building Information Modelling (BIM) is an innovation that provides tools, software technologies for construction professionals and organizations to perform their roles. It provides processes for performing those roles; and provides management tools, principles and platforms for managing the delivery of construction projects.

i. **Category of the project**: (a) Roads [ ] (b) Dam [ ] (c) Bridge and culvert [ ] (d) Buildings for domestic use [ ] (e) Institutional buildings [ ] (f) Industrial buildings [ ] (g) Commercial buildings [ ] (h) Railways and Tunnels [ ] (i) Airports [ ] (j) Ports and Harbours [ ] (k) Others [Please Specify]……………….

ii. **Type of client for the project:** (a) Private sector [ ] (b) Public corporation [ ] (c) National department [ ] (d) Provincial department [ ] (e) Metropolitan department [ ] (f) Regional/District department [ ] (g) Public private partnership [ ] (h) Others…………. [Please indicate]

iii. **Duration of the project:** (a) Less than 3 months [ ] (b) 3 – 6 months [ ] (c) 6 – 1 year [ ] (d) 1 year and above [ ] (e) Others………………. [Please indicate]

iv. **Size of the project consulting team:** [e.g 5 members]………………………………………

v. **Project size/tender sum**: (a) Below R 2Million [ ] (b) R 2Million – R 6.5Million [ ] (c) R 6.5Million – R 40Million [ ] (d) Above R 40Million [ ]

vi. **Project milestones and deadlines:** (a) Flexible milestone and deadline (refers to target dates that are not fixed but created as the project proceeds) [ ] (b) Aggressive milestone and deadline (refers to target dates that are fixed and pursued in a determined and forceful way) [ ] (c) Ambitious milestone and deadline (refer to target date that are fixed based on high aspirations and are difficult to achieve) [ ] (d) Over-ambitious milestone and deadline (refer to target dates that are fixed based on very high aspirations and are very difficult to achieve) [ ]

vii. **Construction technologies and systems used for the project:** (a) Conventional technologies and systems [ ] (b) Proven but new technologies and systems [ ] (c) Unproven and new technologies and systems [ ] (d) Innovative/ground-breaking technologies and systems [ ]

viii. **Political and cultural sensitivity of the project [Refers to the need to acknowledge cultural differences of workers or the public; need to be politically correct; need to relate well with the government in power; need to manage contract problems, labour unrest, hostile press, political violence, riots, and terrorist attacks]:** (a) No political and cultural implications [ ] (b) Little political and cultural implications [ ] (c) High political and cultural implications [ ] (d) Very high political and cultural implications [ ]

ix. **Regulatory requirements:** (a) Standard regulations [ ] (b) Technologies that need new regulatory requirements [ ]

x. **Supply chain stakeholders for the project:** (a) Architect [ ] (b) Structural/Civil engineer [ ] (c) Mechanical engineer [ ] (d) Electrical engineer [ ] (e) Town planner [ ] (f) Quantity surveyor [ ] (g) Facilities manager [ ] (h) Main contractor [ ] (i) BIM manager/Project manager [ ] (j) Steelwork subcontractor [ ] (k) Ductwork subcontractor [ ] (l) Curtain wall subcontractor [ ] (m) Precast products supplier [ ] (n) Flooring specialist [ ] (o) Others………………. [Please indicate]

xi. The following items describe the Level of Development of the information models for construction projects on which BIM is adopted. Kindly indicate the Level of Development of the information models used for the project (Please tick all that is applicable).

Level of Development of the information models	✓
LoD 100 – approximate information	
LoD 200 - information for design and analysis	
LoD 300 – information for measurement, costing and bidding	
LoD 350 – information for coordination and interface management	
LoD 400 – detailed information for assembly, installation, and fabrication	

LoD 500 – detailed information for operations and maintenance	

xii. Please indicate the type of collaborative procurement process that was used for the project (Please tick all that is applicable).

Collaborative procurement	✓
Design-Bid-Build	
Design, Build, Finance and Operate	
Management Contract	
Build-Own-Operate	
Design & Build	
Build-Operate and Transfer	
Build-Operate-Lease and Transfer	
Build-Own-Operate and Transfer	
project partnering and alliancing	
Integrated Project Delivery system	

xiii. How was the project team formed for the project? (Please tick all that is applicable).

Team composition	✓
In-house project team /project team staffed internally [or permanent supply chain]	
Integrated project team/ project team staffed with internal and external members [or two or more supply chain networks] but with different contracts	
Integrated supply team/ project team staffed with internal and external members [or two or more supply chain networks] with a single contract	
Collaborative supply team/ project team staffed with internal and external members [or two or more supply chain networks] in conjunction with subcontractors and specialist suppliers, and with a single contract	

xiv. Kindly indicate the modalities for sharing the cost of software technologies, hardware, technical support, training, and services incurred for BIM adoption on the projects. (Please tick all that is applicable)

Modalities for sharing the cost of BIM adoption	✓
Client - 0% : Project team - 100%	
Client - 10% : Project team - 90%	
Client - 20% : Project team - 80%	
Client - 30% : Project team - 70%	
Client - 40% : Project team - 60%	
Client - 50% : Project team - 50%	

xv. The following items describe the software technologies that are normally used for construction projects on which BIM is adopted. Please indicate the software technologies that were used for the project (Please tick all that is applicable).

Software technologies	✓
Revit	
ArchiCAD	
Allplan	
Solibri	
Synchro Pro	
Vico	
Bentley	
Naviswork	

Zutec	
Glue	
QSCAD	
CYPECAD	
Dimensionx	
Robot	
Tekla Structures	
ITwo	
COSTX	
Fleep	
Box	
Skype for Business	
TIBBR	
Kyklond	
Collaborative solutions	
Aconex	
ViewPoint Colaboration	
Zutec	
Maclaren	
Tekla BIMSight	
BIMx	
VICO	
ViewPoint Collaboration	
Autodesk Naviswork	
Aconex	
Graphisoft Solibiri	
Asite	
EcoDesigner	
Ecotect Analysis	
Onuma	
Archibus	
ArchiFM	
Manhattan	
3D Studio Max	
Sketch UP	
ArtLantic	
Rhinoceros	
Cinema-4D	
Maxwell Render	
Lumion	
MAYA	
Presto	
Candy QTO	
Digital Project	
JOIN.ME	
WORKFRONT	
SLACK	
SHAREPOINT	
CHATTER	
Buildcloud	
Causeway	
Trimble Connect	
NewForma	
RIBProject Centre	

xvi. At what stage of the project were the software technologies used [Please tick all that is applicable].

Project stage	✓

Feasibility stage	
Conceptual stage	
Planning stage	
Design stage	
Construction stage	
Completion and commissioning stage	
Operation and management stage	
De-construction/demolition stage	
Other (please specify)	

xvii. The following items describe the principles that are applicable to a BIM-based project. Please indicate the BIM principles that were adhered to on the project [Please tick all that is applicable]

BIM principles	✓
Supply chain integration [cooperation and communication among the project supply chain]	
Information sharing and exchange among the supply chain	
Multidisciplinary collaboration [trust and teamwork among the supply chain]	
Knowledge sharing and transfer among the supply chain	
Creation of federated/integrated building information models [design review, clash detection, data interoperability, the creation of a project database]	
Creation of discipline-specific building information models	
Client participation in project delivery	
Information coordination and management [BIM protocols]	

xviii. At what stage of the project were the BIM principles applied to the project [Please tick all that is applicable]

Project stage	✓
Feasibility stage	
Conceptual stage	
Planning stage	
Design stage	
Construction stage	
Completion and commissioning stage	
Operation and management stage	
De-construction/demolition stage	
Other (please specify)	

xix. The following items describe the skills and competence required to utilize BIM on construction projects. Kindly rate the skills and competence that were required on the project. (Where 5= Experienced Level; 4= Specialist Level; 3= Expert Level; 2= Functional Level; 1= Entry Level).

Skills and competence	**Experienced level 5**	**Specialist level 4**	**Expert level 3**	**Functional level 2**	**Entry level 1**
Multi-disciplinary collaboration skills					
Information exchange skills					
Information integration skills					
Competence in 3D CAD tools and software technologies					
Competence in BIM tools and software technologies					

xx. The following items describe the tools that are employed for construction projects on which BIM is adopted. Please rate the extent of the use of the following tools on the project. (Where 5=To a Large Extent; 4=Moderate Extent; 3=Some Extent; 2=Rarely; 1=Not At All).

BIM tools	**To a Large Extent 5**	**Moderate Extent 4**	**Some Exten t 3**	**Rarely 2**	**Not At All 1**
Visualization/rendering,					
Virtual mock-up models					
Fabrication models [digital fabrication]					
3D-object based models					
Construction simulation					
Optimization					
Construction sequencing					
Clash detection and model checking					
4D scheduling					
Life-cycle costing					
Budget simulation					
Automatic cost data extraction					
Automatic quantification					
Forensic analysis					
Life cycle analysis					
As-built BIM model					
Intelligent asset management					
Automatic cost data update					
Laser scanning					
Ground penetration radar conversions					
Animation					
Walkthroughs					
BIM maintenance plans and technical support					
Sustainable element tracking					
LEED tracking					
Conceptual energy analysis					
Detailed energy analysis					
BIM embedded operation and maintenance manuals					
CoBie data population and extraction					

xxi. The following items describe the level of clarity of objects that are used to develop information models for construction projects on which BIM is adopted. Kindly rate the following level of objects' clarity was used to develop information models for the project. (Where 5=To a Large Extent; 4=Moderate Extent; 3=Some Extent; 2=Rarely; 1=Not At All).

Level of details (level of clarity of objects)	**To a Large Extent 5**	**Moderate Extent 4**	**Some Extent 3**	**Rarely 2**	**Not At All 1**
G0 – Schematic (description only)					
G1 – Concept (description & dimension only)					
G2 – Defined (description, dimension, manufacturer's details & model's details)					
G3 – Rendered (description, dimension, manufacturer's details,					

model's details & image)					

xxii. The following items describe the various types of information model that are developed for construction projects on which BIM is adopted. Kindly rate the information models that were developed for the project.

Information model developed	**To a Large Extent 5**	**Moderate Extent 4**	**Some Extent 3**	**Rarely 2**	**Not At All 1**
Architectural information model					
Structural information model					
Lighting analysis information model					
Energy analysis information model					
Mechanical services information model					
Electrical services information model					
Construction health and safety information model					
Construction plan and time schedule					
Construction system information model					
Crane assignment information model					
Maintenance and operation schedule					
Cost and quantities information model					
Sustainability analysis information model					
Structural steelwork fabrication information model					
Mechanical system ductwork fabrication information model					
Curtain walling fabrication information model					
Rain screens fabrication information model					
Pre-cast panels fabrication information model					
Glazing system fabrication information model					

xxiii. The following items describe the success criteria attributable to construction projects on which BIM is adopted. Please rate the frequency of use of the following success criteria in assessing the performance of the project. (Where 5=Very Frequently; 4=Frequently; 3= Occasionally; 2= Rarely; 1=Very Rarely).

Success criteria for projects	**Very Frequently 5**	**Frequently 4**	**Occasionally 3**	**Rarely 2**	**Very Rarely 1**
Improved information quality					
Competitive advantage					
Improved team culture					
Enables e-procurement of materials and components					
Supply chain integration					
Improved energy performance					
Improved safety management					
Integrated and interactive database					
Enhanced data interoperability					
Eliminate waste					
Increased knowledge transfer					
Increased information exchange					
Intelligent documentation					
Easy retrieval of building data					
Performance simulation					
Improved prefabrication					

Improved deconstruction management					
Effective supply chain management					
Improved operation and maintenance of facilities					
Enhanced service quality					
Coordinated decision-making					
Trust and commitment					
Allows design review					
Allows clash detection					
Improved work quality					
Increased labor productivity					
Broaden the understanding of project needs					
Fewer request for information					
Fewer change order					
Improved client satisfaction					
A valued and quick decision-making process					
Reduced contractual claims					
Improved marketing					
Improved client participation					
Improved schedule management					
Improved cooperation					
Provide time database					
Improved professional attitude					
Effective communication					
Improved cost control and management					
Improved profit margin					
Fast project delivery					

B: LEVELS OF INTEGRATION AND COLLABORATION AMONG CONSTRUCTION PROJECT SUPPLY CHAIN STAKEHOLDERS

i. How do you evaluate the occurrence of the following trust-based relationships among the organizations and team members that participated on the project?

	To a Large Extent 5	**Moderate Extent 4**	**Some Extent 3**	**Rarely 2**	**Not At All 1**
Consistent integrity					
Competence of personnel					
Competence of organizations					
Problem solving ability					
Openness in sharing information					
Social interaction between supply chain members					
Cross-functional cooperation					
Work interaction between supply chain members					
Absence of racism					
Absence of tribalism					
Absence of professional stereotypes					
Emotional interaction between the project team					
Display of confidence for each other by supply chain members					
Compensating for each other's weaknesses					
Exploiting each other's strengths					
Freedom to state opinions and perspectives					
Absence of competing interests					
Non misuse of information by supply chain members					

Persistence of relationship after projects					
Lack of confrontation and adversarial relationship					
Honesty and mutual commitment					
Conflict resolution					
Risk sharing					
Shared interests and project expectations					
Absence of defensive behaviour					
Mutual exchange of ideas					
Mutual rewards and benefits					
Support for innovation and learning					
Inter-personal relationship					
Inter-organizational relationship					

ii. How do you evaluate the occurrence of information sharing and exchange among the organizations and team members that participated on the project?

	To a Large Extent 5	**Moderate Extent 4**	**Some Extent 3**	**Rarely 2**	**Not At All 1**
Enhanced interpersonal sharing and exchange of information					
Usage of consistent data structures and definitions					
Non-withholding of information					
Cross-boundary information sharing/enhanced inter-organizational sharing and exchange of information					
Non-distortion or manipulation of information					
Usage of collaborative electronic media for information sharing					
Clarity of information					
High quality of information					
Creation of homogeneous or single project information database					
Selection of information sharing channels					
Usage of information sharing protocols					
Adequacy of information					
Timely sharing of information					
Information shared is accurate					
Information shared is credible					
Usage of information exchange format for integrating project information					
Flawless information exchange					
File-based data interoperability					
Server- based data interoperability					
Linking and integration of project information/ data federation					
Absence of conflicting information					

iii. Kindly rate the following communication network among the organizations and team members that participated on the project?

	To a Large Extent 5	**Moderate Extent 4**	**Some Extent 3**	**Rarely 2**	**Not At All 1**
Formation of open and formal communication channels					
Adoption of common electronic communication platforms					
Establishment of a secured line of communication					
Documentation of communication					
Usage of communication protocols					
Adoption of joint problem solving techniques					

Open-ending structured e-meeting					
Agenda-driven structured e-meeting					
Real time communication					
Reciprocal flow of information					
Multi-directional flow of information					
Feedback communication					
Regular interpersonal communication					
Flexibility of formalities					
Regular inter-organizational communication					
Positive corporate communication					
Regular inter-group communication					
Timely communication					
Regular team communication					
Communication across the stages in the project life-cycle					
Problem-solving structured e-meeting					

iv. Kindly rate the occurrence the following knowledge sharing and transfer among the organizations and team members that participated on the project?

	To a Large Extent 5	**Moderate Extent 4**	**Some Extent 3**	**Rarely 2**	**Not At All 1**
Understanding of information					
High quality of information					
Willingness to share resources					
Database creation and management					
Inter-personal knowledge sharing					
Usage of collaborative electronic media for knowledge sharing					
Extraction of cost information from information models					
Inter-professional knowledge sharing					
Extraction of measurement information from the information models					
Inter-organizational knowledge sharing					
Identification of clashes and omission in information models					
Inter-group knowledge sharing					
Extraction of tendering/bidding information from the information models					
Extraction of fabrication information from the information models					
Parametric and object-oriented design of information models					
Review of projects after completion					
Inter-team knowledge sharing					
Extraction of installation information from the information models					
Extraction of operation and maintenance information from the information models					
Sharing of project reviews among supply chain members					
Sharing of project lesson learned among supply chain members					
Quick decision-making					
Valued decision-making					
Collective decision-making					
Sharing of knowledge on best practices among the supply chain members					
Sharing of collaborative experiences among the supply chain					

members					
Extraction of manufacturer's details from the information models					
Sharing of insights among the supply chain members					
Knowledge documentation in form of project proceeding					

C: BIM IMPLEMENTATION STRATEGIES IN USE IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

i. Kindly rate the following commitment strategies used by the top management of your organization towards ensuring the adoption of BIM on the project (Where 5=Very Frequently; 4=Frequently; 3= Occasionally; 2= Rarely; 1=Very Rarely).

	Commitment to BIM implementation	**Very Frequently 5**	**Frequently 4**	**Occasionally 3**	**Rarely 2**	**Very Rarely 1**
1	Coordination of BIM process in the organization					
2	Provision of incentives (bonus & allowance) for BIM usage					
	Provision of incentives for BIM capacity development					
3	Sanctions (queries & demotion) for resistance towards BIM usage					
4	Provision of in-house BIM training					
5	Adaptation of BIM concepts to the organizational culture					
6	Exploration of the usage of BIM on pilot projects					
7	Provision of infrastructures (BIM environment) for BIM					
8	Provision of technical support services in the organization					
9	BIM consultants engagement					
10	Incorporation of BIM into the vision of the organization					
11	Facilitate solutions to projects contingencies (incidents & challenges) brought about by BIM adoption					
	Facilitate solutions to clients contingencies (incidents & challenges) brought about by BIM adoption					
	Facilitate solutions to organizations contingencies (incidents & challenges) brought about by BIM adoption					
12	Documentation of the proceedings of BIM-based projects					
13	Revision of reward system					
	Revision of wage structure					
14	Effective communication between stakeholders					
15	Stimulating BIM adoption with investments					
16	Introduction of new roles and job titles					
17	Introduction of collaborative teamwork culture in the organization					
18	Allowing staff members to participate in the work process redesign process					
19	Increment in staff development budget					
20	Educating staff on the potentials of BIM					
21	Development of new values					
	Development of new management processes					
	Development of communication styles					
22	Creation of new organizational structure					
23	Appointing BIM champions					
	Appointing BIM managers					
24	Anticipating and planning for BIM adoption risk management					
25	Development of performance measures for BIM adoption					

26	Identification of business opportunities in BIM adoption					
27	Ensuring effective use of BIM tools					
28	Adherence to BIM protocols					
	Adherence to BIM process					

ii. Kindly rate which of the following statements describe the motivation to adopt BIM on the project (Where 5=Highly Agree; 4=Agree; 3=Neutral; 2=Disagree; 1=Highly Disagree).

	Motivations for BIM adoption	**Highly Agree 5**	**Agree 4**	**Neutral 3**	**Disagree 2**	**Highly Disagree 1**
1	Prevalent BIM adoption among top and successful firms					
2	BIM adoption by rival firms					
3	BIM adoption among peer firms					
4	BIM adoption as a corporate social responsibility strategy					
	BIM adoption as a way of supporting development in the construction industry					
	BIM adoption as a conformity to regulations and rules					
5	BIM adoption as part of clients' requirement					
6	BIM adoption as part of project team requirement					
7	Government sponsored BIM-based pilot projects					
8	Mandatory requirement of BIM for building permit application					
9	Mandatory requirement of BIM in contractor selection process					
10	BIM adoption as a marketing strategy					
11	Report of BIM usage on a widely acclaimed successful projects					
12	Possibility of getting high value clients					
13	BIM adoption as a requirement in the company's supply chain network					
14	Publication of BIM success stories					
15	Availability of legalities and copyright ownership of BIM					
16	Availability of guidelines on BIM protocols					
17	Availability of fund to assist small and medium firms to adopt BIM					
18	Availability of guidelines on BIM roles and responsibilities (BIM supply chain)					
19	Availability of information on BIM concepts					
20	Advocacy and campaign for BIM					
21	Marketing of BIM as professional services					
22	Advertisement and programs for BIM awareness					
23	Availability of BIM proficient graduates					
24	Availability of national BIM standards					
25	Need to be seen as being up-to-date and technologically sophisticated					
26	Need to be socially acceptable to the clients					
27	Need to adapt to global best practices and trends					
	Need to adapt to global trends					
28	Need to improve organizational performance and efficiency in short terms					
	Need to improve organizational performance and efficiency in long terms					
29	Need to improve competitiveness in project bidding					

iii. Please rate which of the following statement describes the strategies in use by your organization for developing the capacity of your employees to use BIM tools, technologies, and process on the project.

	Developing employees' capacities for BIM	**Highly Agree 5**	**Agree 4**	**Neutral 3**	**Disagree 2**	**Highly Disagree 1**
1	Upbringing by BIM proficient parents					
2	Pre-labour market-influenced BIM training					
3	Self-initiated BIM training					
4	BIM workshops					
	BIM seminars					
5	BIM research and development					
6	On-the-job BIM training for the employees					
7	2D and 3D CAD education in the secondary school					
8	BIM education at undergraduate programme in the university					
9	BIM technology educational programme in colleges, technical and vocational institutes					
10	Corporate BIM training partners					
11	Peer-group-influenced BIM training					
12	BIM application and management programme at post-graduate level in the university					
13	BIM training during Industrial Training/Internship					

iv. Which of the following statements describes the approach to BIM utilization on the project.

	Utilization of BIM on projects	**Highly Agree 5**	**Agree 4**	**Neutral 3**	**Disagree 2**	**Highly Disagree 1**
1	Determining the appropriate BIM maturity levels [3D, 4D, 5D, 6D] for the project					
2	Sharing BIM cost and benefits between the client and the supply chain members					
3	Determining the appropriate number of professionals to form the construction project supply chain network					
	Determining the appropriate types of professionals to form the construction project supply chain network					
4	Determining the required BIM capacity of the construction project supply chain members based on the project type					
5	Determining the appropriate collaborative procurement system					
6	Determining the appropriate level of development of building information models					
7	Assessing the performance of BIM adoption on the project					
8	Determining the appropriate form of collaboration required for the project					
	Determining the appropriate intensity of collaboration required for the project					
9	Determining the appropriate import and export file format for the project					
10	Developing digital object identifiers for building materials manufacturers					

	Developing digital object identifiers for supply chain members					
11	Determining the appropriate BIM platform for the project					

D: BARRIERS TO BIM ADOPTION ON CONSTRUCTION PROJECTS

i. Barriers to BIM adoption are the obstacles preventing the organizations in the construction industry from adopting BIM tools, technologies and process in their organizational work process and utilizing BIM platforms for construction project delivery.

Barriers to preliminary BIM adoption refer to the obstacles preventing the efforts to explore the use of BIM on construction projects.

Kindly rate the occurrence of the following barriers on the project (Where 5= Very High; 4=High; 3=Neutral; 2=Low; 1=Very Low).

	Barriers to preliminary BIM adoption	**Very High** 5	**High** 4	**Neutral** 3	**Low** 2	**Very Low** 1
	Lack of awareness of BIM					
	Lack of understanding of BIM					
	Absence of in-house BIM competent professionals					
	Lack of resources to train employees					
	Unavailability of BIM competent professionals in the labour market					
	Lack of business case for BIM adoption					
	Non-communication of BIM concept by relevant industry leadership					
	Lack of resources to acquire BIM tools and technologies					
	Clashes in professional responsibility in BIM					
	Lack of clarity of professional roles in BIM					
	Lack of policies and regulations on copyright ownership					
	Lack of enforcement from government agencies					
	Lack of enforcement from industry leaderships					
	Lack of cooperation among professionals in the industry					
	Lack of cooperation among firms in the industry					
	Lack of trust among professionals in the industry					
	Lack of trust among firms in the industry					
	Unavailability of BIM guidelines and standards					
	Incompatibility and interoperability of BIM software technologies					
	Lack of BIM awareness among clients					
	Lack of interests in BIM among clients					
	Satisfaction with existing work methods and process					

ii. Barriers to sustained BIM adoption refer to the obstacles preventing the continuous usage of BIM at various stages of construction projects. Kindly rate the occurrence of the following barriers on the project. (Where 5= Very High; 4=High; 3=Neutral; 2=Low; 1=Very Low).

	Barriers to sustained BIM adoption	**Very High** 5	**High** 4	**Neutral** 3	**Low** 2	**Very Low** 1
	Scepticism about benefits of BIM adoption					
	Lack of framework for BIM platforms selection					
	Lack of understanding and identification of BIM tools and					

	technologies					
	Lack of information on BIM tools and technologies					
	Lack of collaborative teamwork culture in the organization					
	Top management not engaging BIM consultants to facilitate BIM usage					
	Unavailability of BIM infrastructures in the organization					
	Failure to understand how BIM adoption will change business processes					
	Lack of coordination(BIM champion or steering committee) across different functional areas					
	Lack of coordination(BIM champion or steering committee) across different supply chain members					
	Conflict of interests between BIM adoption and organizational vision and objectives					
	Inappropriate change management processes within the organization					
	Unavailability of BIM implementation experts (BIM consultants)					
	Employees' unwillingness to accept changes					
	Inadequacy of BIM to support the existing organizational work					
	Inadequacy of BIM to support the existing business process					
	Inadequacy of BIM to meet project expectations					
	Inadequacy of BIM to meet clients' expectations					
	Inadequacy of BIM to meet organizational expectations					
	Lack of clear strategy for BIM usage on projects					
	Fear of loss of competitive advantage					
	Perspective of BIM as just a technology					
	Lack of incentives (bonus & allowance) for workers					
	Lack of patience and understanding of the structural changes needed in the organization					
	Lack of patience and understanding of the cultural changes needed in the organization					
	Lack of awareness of the competitive situation of the firms					
	Lack of capacity to meet BIM implementation demands					
	Rigidity of organizational structures (non-creation of new work sections/job roles in the organization)					

E: INDICATORS OF A REDUCTION IN BARRIERS TO BIM ADOPTION ON CONSTRUCTION PROJECTS

i. The following items describe the indicators of a reduction in barriers to BIM adoption on construction projects. Kindly rate your level of agreement with the occurrence of these indicators on the project (Where 5=Highly Disagree; 4=Disagree; 3=Neutral; 2=Agree; 1=Highly Agree).

Indicators of reduction in BIM adoption barriers	**Highly Disagree 5**	**Disagree 4**	**Neutral 3**	**Agree 2**	**Highly Agree 1**
Awareness of BIM by Construction Project Supply Chain (CPSC) stakeholders					
Understanding of BIM concepts by CPSC stakeholders					
Availability of BIM competent professionals in the labor market					
Regular organization of BIM workshop by regular industry leadership					
Availability of policies and regulations on copyright ownership					

Availability of national BIM guidelines					
Availability of national BIM standards					
Availability of interoperable BIM software technologies					
Awareness of BIM by clients					
Availability of in-house BIM competent professionals					
Acquisition of resources for BIM training of employees					
Acquisition of BIM software technologies					
Evidence of collaborative teamwork culture in the organizations					
Appointment of BIM champion or steering committee					
Availability of BIM infrastructures in the organizations					
Aligning organizational vision and objectives with BIM adoption					
Employees' readiness to accept changes					
Acceptance of BIM competency as a competitive advantage					
Availability of motivation for workers towards BIM adoption					
Aligning organizational structures with BIM adoption requirements					
Aligning organizational culture with BIM adoption requirements					
BIM-induced changes in construction business process					
Understanding of roles in BIM adoption by CPSC stakeholder					
Understanding of responsibilities in BIM adoption by CPSC stakeholder					
Enforcement of BIM adoption on projects by public clients					
Enforcement of BIM adoption on projects by private clients					
Enforcement of BIM adoption on public-private projects					
Availability of information on the selection of BIM software technologies for projects					
Aligning project expectations with BIM potentials					
Acceptance of BIM as a work process					
Acceptance of BIM as a construction management process					
Application of BIM tools to projects					

F. BIM IMPLEMENTATION STRATEGIES FOR ENSURING BIM ADOPTION ON CONSTRUCTION PROJECTS.

i. The following strategies describe the quality of dedication required from the top management of organizations in the construction industry towards BIM adoption on construction projects.

Please rate your level of agreement with the usefulness of these strategies in ensuring the adoption of BIM on construction projects.

	Commitment to BIM adoption	**Strongly Agree 5**	**Agree 4**	**Neutral 3**	**Disagree 2**	**Strongly Disagree 1**
1	Coordination of BIM process in the organization					
2	Provision of incentives (bonus & allowance) for BIM usage					
	Provision of incentives for BIM capacity development					
3	Sanctions (queries & demotion) for resistance towards BIM usage					
4	Provision of in-house BIM training					
5	Adaptation of BIM concepts to the organizational culture					
6	Exploration of the usage of BIM on pilot projects					
7	Provision of infrastructures (BIM environment) for BIM					
8	Provision of technical support services in the organization					

9	BIM consultants engagement					
10	Incorporation of BIM into the vision of the organization					
11	Facilitate solutions to projects contingencies (incidents & challenges) brought about by BIM adoption					
	Facilitate solutions to clients contingencies (incidents & challenges) brought about by BIM adoption					
	Facilitate solutions to organizations contingencies (incidents & challenges) brought about by BIM adoption					
12	Documentation of the proceedings of BIM-based projects					
13	Revision of reward system					
	Revision of wage structure					
14	Effective communication between stakeholders					
15	Stimulating BIM adoption with investments					
16	Introduction of new roles and job titles					
17	Introduction of collaborative teamwork culture in the organization					
18	Allowing staff members to participate in the work process redesign process					
19	Increment in staff development budget					
20	Educating staff on the potentials of BIM					
21	Development of new values					
	Development of management processes					
	Development of communication styles					
22	Creation of new organizational structure					
23	Appointing BIM champions					
	Appointing BIM managers					
24	Anticipating and planning for BIM adoption risk management					
25	Development of performance measures for BIM adoption					
26	Identification of business opportunities in BIM adoption					
27	Ensuring effective use of BIM tools					
28	Adherence to BIM protocols					
	Adherence to BIM process					

ii. The following strategies describe the motivation required by the organizations in the construction industry to adopt BIM tools, technologies, process, and platforms on construction projects. Please rate your level of agreement with the usefulness of these strategies in ensuring the adoption of BIM on construction projects.

	Motivations for BIM adoption	**Strongly Agree 5**	**Agree 4**	**Neutral 3**	**Disagree 2**	**Strongly Disagree 1**
1	Prevalent BIM adoption among top and successful firms					
2	BIM adoption by rival firms					
3	BIM adoption among peer firms					
4	BIM adoption as a corporate social responsibility strategy					
	BIM adoption as a way of encouraging development in the construction industry					
	BIM adoption as a conformity to regulations and rules					
5	BIM adoption as part of clients' requirement					
6	BIM adoption as part of project team requirement					
7	Government sponsored BIM-based pilot projects					
8	Mandatory requirement of BIM for building permit application					
9	Mandatory requirement of BIM in contractor selection					

	process					
10	BIM adoption as a marketing strategy					
11	Report of BIM usage on a widely acclaimed successful projects					
12	Possibility of getting high value clients					
13	BIM adoption as a requirement in the company's supply chain network					
14	Publication of BIM success stories					
15	Availability of legalities and copyright ownership of BIM					
16	Availability of guidelines on BIM protocols					
17	Availability of fund to assist small and medium firms to adopt BIM					
18	Availability of guidelines on BIM roles and responsibilities (BIM supply chain)					
19	Availability of information on BIM concepts					
20	Advocacy and campaign for BIM					
21	Marketing of BIM as professional services					
22	Advertisement and programs for BIM awareness					
23	Availability of BIM proficient graduates					
24	Availability of national BIM standards					
25	Need to be seen as being up-to-date and technologically sophisticated					
26	Need to be socially acceptable to the clients					
27	Need to adapt to global best practices and trends					
28	Need to improve organizational performance and efficiency in short terms					
	Need to improve organizational performance and efficiency in long terms					
29	Need to improve competitiveness in project bidding					

iii. The following statements describe the strategies for developing the capacity of employees to use BIM tools and technologies on construction projects. Please rate your level of agreement with the usefulness of these strategies in ensuring the adoption of BIM on construction projects.

	BIM Capacity Development strategies	**Strongly Agree 5**	**Agree 4**	**Neutral 3**	**Disagree 2**	**Strongly Disagree 1**
1	Upbringing by BIM proficient parents					
2	Pre-labour market-influenced BIM training					
3	Self-initiated BIM training					
4	BIM workshops					
	BIM seminars					
5	BIM research and development					
6	On-the-job BIM training for the employees					
7	2D and 3D CAD education in the secondary school					
8	BIM education at undergraduate programme in the university					

9	BIM technology educational programme in colleges, technical and vocational institutes					
10	Corporate BIM training partners					
11	Peer-group-influenced BIM training					
12	BIM application and management programme at post-graduate level in the university					
13	BIM training during Industrial Training/Internship					

iv. The following items describe the strategies for strategic adoption of BIM on construction projects. Please rate your level of agreement with the usefulness of these strategies in ensuring the adoption of BIM on construction projects.

	Utilization strategies for BIM adoption on projects	**Strongly Agree 5**	**Agree 4**	**Neutral 3**	**Disagree 2**	**Strongly Disagree 1**
1	Determining the appropriate BIM maturity levels [3D, 4D, 5D, 6D] for different types of project complexities					
2	Sharing BIM cost and benefits between the client and the supply chain members					
3	Determining the appropriate professionals to form the construction project supply chain network					
	Determining the appropriate types of professionals to form the construction project supply chain network					
4	Determining the required BIM capacity of the construction project supply chain members based on the types of project					
5	Determining the appropriate collaborative procurement system for different types of project complexities					
6	Determining the appropriate level of development of building information models for different types of project complexities					
7	Assessing the performance of BIM adoption on construction projects					
8	Determining the appropriate form of collaboration required for different types of project complexities					
	Determining the appropriate intensity of collaboration required for different types of project complexities					
9	Determining the appropriate import and export file format for different types of project complexities					
10	Developing digital object identifiers for building materials manufacturers					
	Developing digital object identifiers for supply chain					

APPENDIX D: INTERVIEW GUIDE

Researcher: OLUGBOYEGA Oluseye OLGOLU005@myuct.ac.za; oolugboyega@yahoo.com

Supervisor: Prof. WINDAPO Abimbola abimbola.windapo@uct.ac.za

Context: *Thank you for agreeing to participate in this interview. The interview is designed to learn more about the appropriate strategies for Building Information Modelling [BIM] implementation in the construction industry.*

Ethical considerations: *Participation in this interview is voluntary. Data collected in this interview will not be shared with anyone and will be used in a combined format.*

Premise: *Integration and collaboration among the construction project supply chain (CPSC) stakeholders is an ultimate goal of project management and determine the choice of construction management systems; as they are tied to the success of construction projects, the performance of the CPSC stakeholders, and the efficiency of the construction process. Scholars view that Building Information Modelling (BIM) is an effective collaborative work platform and system that brings about integration and collaboration among the CPSC stakeholders on construction projects. However, the adoption of BIM on construction projects is not widespread, while there is no strategically structured BIM adoption guide available on construction projects for ensuring integration and collaboration among the CPSC stakeholders. The lack of adoption of BIM on construction projects has been adduced to the use of ineffective BIM implementation strategies. Furthermore, these strategies are not based on an in-depth investigation of the barriers to sustained BIM adoption and non-usage of a multi-dimensional approach.*

NOTE: *BIM is an innovation that provides software technologies for CPSC stakeholders to perform their roles, provides processes and platforms for performing those roles, and serves as management systems for integrating, coordinating and controlling building design, construction and operation activities.*

A: INTRODUCTORY QUESTIONS [These are personal questions]

Question 1: Kindly let me know your work responsibilities?

[Answer]……………………………………………………………………………………………
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Question 2: Please highlight your work experience?

[Answer]……………………………………………………………………………………………
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B: MAIN QUESTIONS [These are questions on BIM implementation in the construction industry]

Question 1: What is your understanding of the following components of collaboration among the construction project supply chain stakeholders?

(i) Trust-based relationships
(ii) Knowledge sharing and transfer
(iii) Information sharing and exchange
(iv) Network communication

[Answer]…………………………………………………………………………………………
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Probing question: Are there any other concepts that you would like to add to those presented in question 1?

[Answer]…………………………………………………………………………………………
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Question 2: What is your understanding of the following components of BIM adoption on construction projects?

(i) Success criteria for construction projects
(ii) Skills and competence of construction project supply chain stakeholders
(iii) BIM tools
(iv) Level of details and development
(v) Building information models
(vi) Collaborative procurement process
(vii) Size and formation of project team
(viii) Sharing of BIM cost and benefits
(ix) BIM software technologies
(x) Complexities of construction projects

[Answer]…………………………………………………………………………………………
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Probing question: Are there any other concepts that you would like to add to those presented in question 1?

[Answer]…………………………………………………………………………………………
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Question 3: How do you think BIM adoption on construction projects can be used to achieve integration and collaboration among the supply chain stakeholders?

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Question 4: Which of the following BIM implementation strategies will result in the best integration and collaboration among the supply chain stakeholders, and why?

(i) Commitment to BIM implementation
(ii) Developing employees' capacities for BIM
(iii) Strategic utilization of BIM on construction projects
(iv) Motivations for BIM adoption on construction projects

[Answer]……………………………………………………………………………………………
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Probing question: Are there any other concepts that you would like to add to those presented in question 1?

[Answer]…………………………………………………………………………………………
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Question 5: What are the barriers preventing the project organizations from experimenting with BIM on construction projects?

[Answer]…………………………………………………………………………………………
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Probing question: Are there any other concepts that you would like to add to those presented in question 1?

[Answer]…………………………………………………………………………………………
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Question 6: What do you perceive as the barriers that could prevent the continuous usage of BIM at various stages of a project and on subsequent construction projects?

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Question 7: What are the best strategies for overcoming the barriers to experimenting with BIM on construction projects by project organizations?

[Answer]……………………………………………………………………………………………
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Question 8: What are the best strategies for overcoming the barriers to continuous use of BIM at various stages of a project and on subsequent construction projects?

[Answer]……………………………………………………………………………………………
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Question 9: What are your opinions on strategic use of BIM on construction projects?

[Answer]……………………………………………………………………………………………
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Question 10: How do you think integration and collaboration can be achieved among the supply chain stakeholders?

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Question 11: How would you rate the usage of BIM in achieving integration and collaboration among the supply chain stakeholders?

[Answer]……………………………………………………………………………………………
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Question 12: Kindly describe the impact that BIM adoption on construction projects would have on integration and collaboration among the supply chain stakeholders?

[Answer]……………………………………………………………………………………………
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Question 13: Identify a particular project on which BIM was used. Use the identified project to describe the following project information?

(i) Type of project
(ii) Method of procurement
(iii) Type of client
(iv) Type and number of stakeholders
(v) Duration of the project
(vi) Complexity of the project

[Answer]……………………………………………………………………………………………
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Probing question: Are there any other concepts that you would like to add to those presented in question 1?

[Answer]……………………………………………………………………………………………
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Question 14: How would you rate the level of integration and collaboration among the supply chain stakeholders on the project identified in Question 9?

[Answer]……………………………………………………………………………………………
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Question 11: What BIM implementation strategies were used on the project identified in Question 9?

[Answer]……………………………………………………………………………………………
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Question 15: Do these strategies incorporate consideration for barriers to experimenting with BIM on construction projects and continuous use of BIM at various stages of the project?

[Answer]……………………………………………………………………………………………
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Question 16: In your opinion, is the level of integration and collaboration among the supply chain stakeholders enhanced by the use of BIM on the project identified in Question 9?

[Answer]……………………………………………………………………………………………
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Question 17: In your opinion, does the BIM implementation strategies used on the project (identified in Question 9) impact the level of integration and collaboration among the supply chain stakeholders? If it does, why?

[Answer]……………………………………………………………………………………………
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Question 18: In your opinion, does the BIM implementation strategies used on the project (identified in Question 9) impact the level of BIM adoption on the project? If it does, why?

[Answer]……………………………………………………………………………………………
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Question 19: Does the level of BIM adoption on the project (identified in Question 9) interact with the relationship between BIM implementation strategies, and the levels of integration and collaboration on the project? If it does, why?

[Answer]……………………………………………………………………………………………
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APPRNDIX E: CONSENT FORM

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

Department of Construction Economics and Management
Faculty of Engineering and the Built Environment
University of Cape Town
Level 1.07, Snape Building, Upper Campus
Rondebosch, 7701
Cape Town
August, 2018.

Dear prospective participant,

Re: The Nexus between Building Information Modelling Implementation Strategies, Adoption, and Levels of Construction Supply Chain Stakeholder Integration

You are hereby invited to participate in an ongoing PhD (Construction Economics and Management) research project aimed at examining the barriers to preliminary and sustained BIM adoption decisions, and the use of multi-dimensional approach to BIM adoption, towards developing a framework that will facilitate BIM adoption on construction projects and the best integration and collaboration among the Construction Project Supply Chain stakeholders.

This is a research being undertaken by Olugboyega Oluseye, a PhD student under the supervision of Professor Abimbola Olukemi Windapo of the University of Cape Town. The outcome of the study will be presented to the Department of Construction Economics and Management in fulfilment of the requirement for the award of a Doctor of Philosophy Degree (PhD) in Construction Economics and Management.

This research does not pose any known risks and does not request any sensitive information. This research will provide a comprehension of the relationship between BIM implementation strategies and frameworks and reduction in barriers to preliminary and sustained BIM adoption on construction projects, and the relationship between level of BIM adoption on construction projects and levels of integration and collaboration among CPSC stakeholders. The questionnaire can be completed in approximately 15minutes. All useful comments that will aid the researcher in carrying out the study are welcome. All subjects of this research and any information that you shall provide will be protected with unreserved confidentiality.

Should you have any queries or questions for clarification purposes about the study, do not hesitate to contact me on 072303909 or OLGOLU005@myuct.ac.za. Your timely response will be appreciated.

Thank you for your assistance.

Mr. Olugboyega Oluseye	Prof. Abimbola Olukemi Windapo
(PhD Candidate/Principal Researcher)	(Supervisor)

UNIVERSITY OF CAPE TOWN
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

APPENDIX F: CONSENT LETTER

CONSTRUCTION ECONOMICS AND MANAGEMENT DEPARTMENT

Oluseye OLUGBOYEGA (PhD Candidate)
University of Cape Town
Level 1.07, Snape Building
Upper Campus
Rondebosch, 7701
Cape Town
Cell: +27-767697765
Email: OLGOLU005@myuct.ac.za

CONSENT FORM

<u>Title of the research project:</u>

The Nexus between Building Information Modelling Implementation Strategies, Adoption, and Levels of Construction Supply Chain Stakeholder Integration

Name and position of the researcher:

Oluseye OLUGBOYEGA, PhD Candidate, Department of Construction Economics and Management, University of Cape Town

Please respond to the following:

Please tick

1. I have read Mr. Olugboyega's covering letter and understand what kind of information he is seeking from me.
   kind of information he is seeking from me. ☐

2. I agree to answer the questions posed in this study, and providea ccurate information to the best of my ability.
   a ccurate information to the best of my ability. ☐

3. I understand that my participation is voluntary and that I am free to withdraw at any time without offering reasons.
   to withdraw at any time without offering reasons. ☐

4. I agree to take part in this study. ☐

Name of the participant (on behalf of the company): ………………………………..

Signed: .... Date…………………......................

Oluseye OLUGBOYEGA (principal researcher) Signature: Date: 23/08/2018

NOTE: All the information provided by you on behalf of the company will be treated as strictly confidential. The result will be presented in aggregate format and no individual disclosure will be made.

APPENDIX G: ETHICS COVER LETTER

The traditional construction management systems make the relationship networks among the construction project supply chain (CPSC) stakeholders unstable, fragmented, lacking in trust and harmony, and lacking a feedback mechanism. Building Information Modelling (BIM)-enabled construction management systems have been advertised as the perfect approach for ensuring integration and collaboration among the CPSC stakeholders. Nevertheless, some countries such as South Africa, Japan, Iran, and Nigeria are reluctant to implement BIM. Therefore, this research examines barriers to preliminary and sustained BIM adoption decisions, and the use of multi-dimensional approach to BIM adoption, towards developing a framework that will facilitate BIM adoption on construction projects and the best integration and collaboration among the CPSC stakeholders.

The specific objectives of the study are to investigate the barriers to preliminary and sustained BIM adoption on construction projects; identify the BIM implementation strategies in use; establish the indicators of a reduction in barriers to preliminary and sustained BIM adoption on construction projects; establish the level of BIM adoption on construction projects in terms of project size and complexities, BIM tools, BIM technologies, BIM capacity, information management, BIM process, and project performance assessment; determine the levels of integration and collaboration among the CPSC stakeholders; identify the BIM implementation strategies that will trigger a reduction in the barriers to preliminary and sustained BIM adoption on construction projects; and model the interactions between the levels of integration and collaboration among the CPSC stakeholders, the level of BIM adoption on construction projects, reduction in barriers to preliminary and sustained BIM adoption on construction projects, and BIM implementation strategies.

This research does not pose any known risks and does not request any sensitive information. Ethical issues that may arise from this research include concerns of confidentiality, anonymity, and informed consent. These will be treated by ensuring that the e-mails, phone numbers and names of the participants are not disclosed to a third party. Also, participation in the survey will be voluntary.

APPENDIX H: APPLICATION FOR APPROVAL OF ETHICS

Application for Approval of Ethic in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		OLUGBOYEGA Oluseye
Department		Construction Economics and Management
Preferred email address of applicant:		OLGOLU005@myuct.ac.za
If Student	Your Degree: e.g., MSc, PhD, etc.	PhD
	Credit Value of Research: e.g., 60/120/180/360 etc.	360
	Name of Supervisor (if supervised):	A/Professor Abimbola Olukemi Windapo
If this is a researchcontract, indicate the source of funding/sponsorship		N/A
Project Title		The Nexus between Building Information Modelling Implementation Strategies, Adoption, and Levels of Construction Supply Chain Stakeholder Integration

I hereby undertake to carry out my research in such a way that:

- there is no apparent legal objection to the nature or the method of research; and
- the research will not compromise staff or students or the other responsibilities of the University;
- the stated objective will be achieved, and the findings will have a high degree of validity;
- limitations and alternative interpretations will be considered;
- the findings could be subject to peer review and publicly available; and
- I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

SIGNED BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	OLUGBOYEGA Oluseye	Signature Removed	23 Aug 2018

APPLICATION APPROVED BY	Full name	Signature	Date
Supervisor (where applicable)	Abimbola Windapo	Signature Removed	23 Aug 2018
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section1; and for all Undergraduateresearch (Including Honours).	Click here to enter text. NIEN-TSU TUAN	Signature Removed	17 Sep. 2018 Click here to enter a date.
Chair : Faculty EiR Committee For applicants other than undergraduate students who have answered YES to any of the above questions.	R Behrens	Signature Removed	17 Sep 2018

Page 1 of 1

APPENDIX I: INTERVIEW TRANSCRIPT

#1

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Page 1: STRUCTURED INTERVIEW

Q1 Kindly let me know your work responsibilities?

Structural Engineer/BIM Manager

Q2 Please highlight your work experience?

5-6year working experience

Q3 What is your understanding of the following components of collaboration among the construction project supply chain stakeholders? (i) Trust-based relationships (ii) Knowledge sharing and transfer (iii) Information sharing and exchange (iv) Network communication

(i) Trust-based relationships
(iii) Information sharing and exchange

Q4 What is your understanding of the following components of BIM adoption on construction projects? (i) Success criteria for construction projects (ii) Skills and competence of construction project supply chain stakeholders (iii) BIM tools (iv) Level of details and development (v) Building information models (vi) Collaborative procurement process (vii)

Size and formation of project team (viii) Sharing of BIM cost and benefits (ix) BIM software technologies (x) Complexities of construction projects

(iii) BIM tools
(viii) Sharing of BIM cost and benefits
(v) Building information models
(ix) BIM software technologies

Q5 How do you think BIM adoption on construction projects can be used to achieve integration and collaboration among the supply chain stakeholders?

It can be used to deliver projects optimally. BIM adoption involves management of models for the extraction of information for the asset to be delivered

Q6 Which of the following BIM implementation strategies will result in the best integration and collaboration among the supply chain stakeholders, and why? (i) Commitment to BIM implementation (ii) Developing employees' capacities for BIM (iii) Strategic utilization of BIM on construction projects (iv) Motivations for BIM adoption on construction projects

(i) Commitment to BIM implementation
(iv) Motivations for BIM adoption on construction projects

Q7 What are the barriers preventing the project organizations from experimenting with BIM on construction projects?

Management and level of training Schemes in place

Q8 What do you perceive as the barriers that could prevent the continuous usage of BIM at various stages of a project and on subsequent construction projects?

BIM Awareness and Skills

Q9 What are the best strategies for overcoming the barriers to experimenting with BIM on construction projects by project organizations?

Must be included in the project management plan and discusses through out the life cycle of the project

Q10 What are the best strategies for overcoming the barriers to continuous use of BIM at various stages of a project and on subsequent construction projects?

Must be included in the project management plan and discusses through out the life cycle of the project

Q11 What are your opinions on the strategic use of BIM on construction projects?

Must be included in the project management plan and discusses through out the life cycle of the project

Q12 How do you think integration and collaboration can be achieved among the supply chain stakeholders?

Clear Project Management Plan and BIM Execution Plan must be discussed

Q13 How would you rate the use of BIM in achieving integration and collaboration among the supply chain stakeholders?

7 of 10

Q14 Kindly describe the impact that BIM adoption on construction projects would have on integration and collaboration among the supply chain stakeholders?

7 of 10

Q15 Identify a particular project on which BIM was used. Use the identified project to describe the following project information? (i) Type of project (ii) Method of procurement (iii) Type of client (iv) Type and number of stakeholders (v) Duration of the project (vi) Complexity of the project

(i) Type of project: Mixed development
(iii) Type of client: Government
(iv) Type and number of stakeholders: 9
(v) Duration of the project: 11months
(vi) Complexity of the project: very complex

Q16 How would you rate the level of integration and collaboration among the supply chain stakeholders on the project identified in Question 18? 6 of 10

Q17 What BIM implementation strategies were used on the project identified in Question 18?

Collaborative Strategy
Communication Plan
Level of BIM Adoption

Q18 Do these strategies incorporate consideration for barriers to experimenting with BIM on construction projects and continuous use of BIM at various stages of the project?

Yes

Q19 In your opinion, is the level of integration and collaboration among the supply chain stakeholders enhanced by the use of BIM on the project identified in Question 18?

Yes

Q20 In your opinion, does the BIM implementation strategies used on the project (identified in Question 18) impact the level of integration and collaboration among the supply chain stakeholders? If it does, why?

Yes

Q21 In your opinion, does the BIM implementation strategies used on the project (identified in Question 18) impact the level of BIM adoption on the project? If it does, why?

Yes

Q22 Does the level of BIM adoption on the project (identified in Question 18) interact with the relationship between BIM implementation strategies, and the levels of integration and collaboration on the project? If it does, why?

Yes; it was intensively adopted throughout the design and construction phase to the handling over phase

#2

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Page 1: STRUCTURED INTERVIEW

Q1 Kindly let me know your work responsibilities?

Digital Lead for Engineering/bim management

Q2 Please highlight your work experience?

20 years in Civil Engineering Consulting

Q3 What is your understanding of the following components of collaboration among the construction project supply chain stakeholders? (i) Trust-based relationships (ii) Knowledge sharing and transfer (iii) Information sharing and exchange (iv) Network communication

I understand these concepts

Q4 What is your understanding of the following components of BIM adoption on construction projects? (i) Success criteria for construction projects (ii) Skills and competence of construction project supply chain stakeholders (iii) BIM tools (iv) Level of details and development (v) Building information models (vi) Collaborative procurement process (vii) Size and formation of project team (viii) Sharing of BIM cost and benefits (ix) BIM software technologies (x)
Complexities of construction projects

I understand these concepts, they apply to our normal work

Q5 How do you think BIM adoption on construction projects can be used to achieve integration and collaboration among the supply chain stakeholders?

When multiple stakeholders contribute to the same set of information, and depend on each other's information updates to progress, it is hoped that there will be greater convergence than when those parties operate in isolation and then try to combine their outcomes.

Q6 Which of the following BIM implementation strategies will result in the best integration and collaboration among the supply chain stakeholders, and why? (i) Commitment to BIM implementation (ii) Developing employees' capacities for BIM (iii) Strategic utilization of BIM on construction projects (iv) Motivations for BIM adoption on construction projects

None of these alone will work. BIM adoption does cost money (training, software, changing processes), it requires different team roles, and if disrupts the Business as Usual way of working. Agreement from the C-site of all affected parties, plus a commitment from the paying client to subsidies the process in part, are important.

Q7 What are the barriers preventing the project organizations from experimenting with BIM on construction projects?

See answer 6

Q8 What do you perceive as the barriers that could prevent the continuous usage of BIM at various stages of a project and on subsequent construction projects?

Different parties are involved during the various stages. The handover of information and ongoing development of the model and associated information requires a unified, standardised approach to the continuous use and (more importantly) the growth of the BIModel. Lack of standards and unified processes are a major problem.

Q9 What are the best strategies for overcoming the barriers to experimenting with BIM on construction projects by project organizations?

Start small

Q10 What are the best strategies for overcoming the barriers to continuous use of BIM at various stages of a project and on subsequent construction projects?

Keep going, even when something doesn't go according to plan

Q11 What are your opinions on the strategic use of BIM on construction projects?

Don't be idealistic, but drive to practical benefits

Q12 How do you think integration and collaboration can be achieved among the supply chain stakeholders?

Use BIM

Q13 How would you rate the use of BIM in achieving integration and collaboration among the supply chain stakeholders?

I would need a scale to rate this.

Q14 Kindly describe the impact that BIM adoption on construction projects would have on integration and collaboration among the supply chain stakeholders?

If done effectively, it should make an improvement

Q15 Identify a particular project on which BIM was used. Use the identified project to describe the following project information? (i) Type of project (ii) Method of procurement (iii) Type of client (iv) Type and number of stakeholders (v) Duration of the project (vi) Complexity of the project

Q16 How would you rate the level of integration and collaboration among the supply chain stakeholders on the project identified in Question 18?

-

Q17 What BIM implementation strategies were used on the project identified in Question 18?

-

Q18 Do these strategies incorporate consideration for barriers to experimenting with BIM on construction projects and continuous use of BIM at various stages of the project?

-

Q19 In your opinion, is the level of integration and collaboration among the supply chain stakeholders enhanced by the use of BIM on the project identified in Question 18?

-

Q20 In your opinion, does the BIM implementation strategies used on the project (identified in Question 18) impact the level of integration and collaboration among the supply chain stakeholders? If it does, why?

-

Q21 In your opinion, does the BIM implementation strategies used on the project (identified in Question 18) impact the level of BIM adoption on the project? If it does, why?

-

Q22 Does the level of BIM adoption on the project (identified in Question 18) interact with the relationship between BIM implementation strategies, and the levels of integration and collaboration on the project? If it does, why?

#3

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Page 1: STRUCTURED INTERVIEW

Q1 Kindly let me know your work responsibilities?

Geotechnical Engineer/bim application

Q2 Please highlight your work experience?

designs

Q3 What is your understanding of the following **Respondent skipped this question** components of collaboration among the construction project supply chain stakeholders? (i) Trust-based relationships (ii) Knowledge sharing and transfer (iii) Information sharing and exchange (iv) Network communication

Q4 What is your understanding of the following **Respondent skipped this question** components of BIM adoption on construction projects? (i) Success criteria for construction projects (ii) Skills and competence of construction project supply chain stakeholders (iii) BIM tools (iv) Level of details and development (v) Building information models (vi) Collaborative procurement process (vii) Size and formation of project team (viii) Sharing of BIM cost and benefits (ix) BIM software technologies (x) Complexities of construction projects

Q5 How do you think BIM adoption on construction projects can be used to achieve integration and collaboration among the supply chain stakeholders?

I think it will be a great tool if well understand by the users

Q6 Which of the following BIM implementation strategies will result in the best integration and collaboration among the supply chain stakeholders, and why? (i) Commitment to BIM implementation (ii) Developing employees' capacities for BIM (iii) Strategic utilization of BIM on construction projects (iv) Motivations for BIM adoption on construction projects

(ii) Because if the program is well understood, it will be used effective

Q7 What are the barriers preventing the project organizations from experimenting with BIM on construction projects?

Poor communication

Q8 What do you perceive as the barriers that could prevent the continuous usage of BIM at various stages of a project and on subsequent construction projects?

Lack of skills. Users have to be taught it's importance

Q9 What are the best strategies for overcoming the barriers to experimenting with BIM on construction projects by project organizations?

Workshops and classes to educate the users about it.

Q10 What are the best strategies for overcoming the barriers to continuous use of BIM at various stages of a project and on subsequent construction projects?

Awareness

Q11 What are your opinions on the strategic use of BIM on construction projects?

It's seems like it's a great tool if well understood

Q12 How do you think integration and collaboration can be achieved among the supply chain stakeholders?

Q13 How would you rate the use of BIM in achieving integration and collaboration among the supply chain stakeholders?

6/10

Q14 Kindly describe the impact that BIM adoption on construction projects would have on integration and collaboration among the supply chain stakeholders?

It not much positive will be felt in the early stages as the users are getting to know and understand about the program.

Q15 Identify a particular project on which BIM was used. Use the identified project to describe the following project information? (i) Type of project (ii) Method of procurement (iii) Type of client (iv) Type and number of stakeholders (v) Duration of the project (vi) Complexity of the project

Not applicable

Q16 How would you rate the level of integration and collaboration among the supply chain stakeholders on the project identified in Question 18?

N/A

Q17 What BIM implementation strategies were used on the project identified in Question 18?

Q18 Do these strategies incorporate consideration for barriers to experimenting with BIM on construction projects and continuous use of BIM at various stages of the project?

Q19 In your opinion, is the level of integration and collaboration among the supply chain stakeholders enhanced by the use of BIM on the project identified in Question 18?

Q20 In your opinion, does the BIM implementation strategies used on the project (identified in Question 18) impact the level of integration and collaboration among the supply chain stakeholders? If it does, why?

Q21 In your opinion, does the BIM implementation strategies used on the project (identified in Question 18) impact the level of BIM adoption on the project? If it does, why?

Q22 Does the level of BIM adoption on the project (identified in Question 18) interact with the relationship between BIM implementation strategies, and the levels of integration and collaboration on the project? If it does, why?