MANAGING MEGA INFRASTRUCTURE COMPLEXITY: A STUDY ON DIGITAL CONSTRUCTION ADOPTION IN NIGERIA

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Abstract

Existing strategies have failed to develop managerial competence in managing megaproject complexities, resulting in underperformance. Although various recommendations have been proposed, most fail to support managers when complexity peaks during infrastructure construction. This study investigated whether digital construction and the integration of technologies, such as Building Information Modelling (BIM), the Internet of Things (IoT), and automation, can enhance project management competence to tackle the complexities associated with mega-infrastructure construction in Nigeria. Employing an exploratory sequential mixed-methods approach, this study addresses a critical knowledge gap regarding complexity management within this developing economy context. The initial quantitative factor analysis of Nigerian project manager surveys revealed prevalent local structural and dynamic complexity drivers. Follow-up expert interviews identified competence crucial for managing multifaceted complexities during mega-construction. Extensive observations across nine active megaprojects and project management surveys provide empirical evidence that digital construction enhances communication, planning, coordination, and other competencies for navigating construction complexity. Inferential analysis further substantiates the significant positive influence of digital construction, particularly in enabling coordination capabilities to manage technical interdependencies, multiple teams, and distributed locations arising from structural complexity. However, substantial gaps exist between the theoretical potential and actual problem-solving impact of digital tools for dynamic complexity uncertainties, often attributed to profound organisational obstacles hindering adoption. Integrating concepts, models, and learning, this study developed an innovative framework for managing complexity in Nigerian mega-construction projects using digital construction. Extensive hypothesis testing and construction expert interviews validated the framework, confirming robust connections between digital construction, competence improvements, enhanced complexity management, and project performance. This study makes significant theoretical and empirical contributions by introducing digital construction as an innovative human-centred strategy tailored to construction needs. It also develops a pioneering categorisation of locally prevalent complexity factors and elucidates the context-specific managerial competencies that are most salient for megaprojects. Overall, this study elucidates pathways for sophisticated, digitally enabled, next-generation project management practices that can address the intricate complexity dynamics inherent in mega-construction projects in developing countries. This can be achieved through strategic adoption of human-centred digital construction.

Keywords: Construction complexity, Digital construction, Project management competence, Mega infrastructure construction, Project strategy, Complexity management, Digital tools

Publications

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Author's Declaration

The material contained within this thesis has not previously been submitted for a degree at the University of Nottingham or any other university. The author has conducted the research in this thesis unless otherwise indicated.

Dedication

The past two years have brought unprecedented challenges globally, as humanity has struggled to fight the severe impact of the COVID-19 pandemic and find a way to recover. With sincere gratitude, I dedicate this work to honouring the cherished memories of those lost to this fierce opponent. May their spirits remain as symbols of love, bravery, and hope to guide us forward.

This work also serves as a simple tribute to healthcare workers, first responders, community leaders, and everyday heroes on the frontlines who have tirelessly given up protecting us. Their strength, kindness, and unwavering commitment to service demonstrate the power of human unity and spirit during tough times. You represent the best of humanity, and we can never repay you fully.

To everyone affected by this crisis, you are in my thoughts and prayers, as we keep dealing with the profound impact. Although the path ahead is challenging, you remember that you are not alone. Through care and cooperation, we will overcome the challenges posed by this global test, regardless of how long it takes.

This work reflects the unyielding power of community and human cleverness to succeed, even in the most difficult trials. May the difficulties of these times sow wisdom, growth, and a renewed understanding of the blessings of health, connection, and meaningful service. The future is in our hands - with hope guiding us, we will build it stronger.

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Abbreviation

3D	Three-dimension
4D	Four-dimension
5D	Five-dimension
AHP	Analytical Hierarchy Process
AR	Augmented Reality
BIM	Building Information Model
CAD	Computed Aided Design
DTC	Digital Twin Construction
FDI	Foreign Direct Investment
FOCI	Federation of Construction Industry
GA	Genetic Algorithms
GIS	Geographical Information System
GPS	Global Positioning System
GVET	Global Virtual Engineering Team
HEI	Higher Education Institutions
ICT	Information and Communication Technology
IPMA	International Project Management Association
OSM	Object Sequencing Matrix and
PMI	Project Management Institute
RFI	Request for Information
RFID	Radio-frequency Identification
RSSI	Received Signal Strength Indication
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
UNPF	United Nations Population Fund
USD	United States Dollars
VDC	Virtual Digital Construction
VR	Virtual Reality
WHO	World Health Organisation

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Chapter 1 Introduction

This chapter introduces the background and rationale of this doctoral research, which focuses on enhancing project management competence to manage complexity during mega-infrastructure construction in Nigeria. This establishes the pivotal role of megaprojects in society and the prevalence of underperformance attributed to unmanaged complexity and inadequate strategies. Gaps in current project management techniques have been synthesised, indicating the potential of innovative digital construction based on manufacturing sector digitalisation. The aligned research questions targeted complexity factors, competence needs, and the influence of digital construction on augmentation. The chapter outlines the aim, objectives, scope, contributions, and thesis structure. Overall, it introduces the background and needs for this research, focusing on advancing project management in Nigeria's developing context through human-centred digital strategies tailored to local complexities.

1.1 Background and Motivation

Megaprojects play a crucial role in driving the advancement and transformation of contemporary society (Gellert & Lynch, 2003). These ambitious endeavours have had a tangible impact on the built environment throughout history, requiring substantial capital outlays, profound technical expertise, and innovation, resulting in significant impacts on socioeconomic conditions upon completion. Scholars, such as Flyvbjerg (2017), describe megaprojects as large-scale, intricate ventures that typically exceed $1 billion in cost, require many years of development and construction, involve diverse stakeholders, are transformative, and benefit millions of people. However, the suitability of the $1 billion threshold has sparked debate, leading to the consideration of classifications based on GDP-related criteria (Hu et al., 2013) and contextual nuances (Van Marrewijk et al., 2008).

From a socio-political perspective, megaprojects warrant scrutiny because of their substantial public expenditure and expected societal implications (Capka, 2006; Flyvbjerg et al., 2017). This scrutiny yielded Frick's (2005) categorisation of megaprojects as the "Six Cs”, denoting Colossal, Captivating, Costly, Controversial, Complex, with Control difficulties (Frick, 2005). This classification aligns with Pollack et al. (2018), who emphasised that megaprojects are more effectively delineated by their inherent complexities, uncertainties, and extended time horizons rather than solely by financial magnitudes. This perspective indicates that complexity attributes can manifest themselves, even in projects with limited resources (Söderlund et al., 2017).

Within this investigation, "megaprojects" refer to extensive undertakings marked by a substantial budget and exert a notable socio-economic impact on their stakeholders. These projects were further categorised as extraction, production, consumption, and infrastructure projects as outlined by Gellert and Lynch (2003). This research focuses on evaluating the transportation, utilities, and building components within the infrastructure sector, as they represent significant investments relative to the GDP of Nigeria and have a profound influence on global urbanisation trends and population growth (Frefer et al., 2018). In response to these trends, mega-infrastructure investment increased to $10 trillion in 2017 and is projected to expand at an annual rate of 3.9% to $17.5 trillion by 2030 (Oxford Economics, 2015).

However, despite the increase in investment in mega-infrastructure, concerns regarding suboptimal performance and the realisation of intended outcomes persist. This aligns with Flyvbjerg's (2017) observation that, based on historical data, numerous projects fail to meet their intended objectives. It is widely acknowledged that developed countries are more adept at managing fluctuations in project performance, as compared to developing nations such as Nigeria, which often face significant challenges in attracting foreign investment - a crucial driver of economic growth. (Sahiti et al., 2018). Nigeria's infrastructure megaprojects are affected by severe underperformance and a failure to meet objectives, mirroring global trends (Mansfield et al., 1994). Balogun (2016) found that mega-infrastructure underperformance is normalised in Nigeria. Scholars attribute these dismal outcomes to deficiencies in project management competence owing to the complexity of megaproject delivery (Onyia, 2019).

In light of the challenges developing countries face in delivering efficient infrastructure despite their intense desire to do so, Othman and Ahmed (2013) highlighted the need to address the complex problems that often arise in implementing and managing mega-infrastructure development projects. Ofori (2015) emphasised the urgency of enhancing management proficiency to navigate this complexity, a view shared by Yahya et al. (2019) from the Nigerian context. The significance of enhancing the proficiency of project managers to better align with the demands of Nigeria's infrastructure development cannot be overstated. This alignment would result in maximising the value derived from every dollar invested in mega-projects, which are critical to meeting the nation's growing population, projected to reach two billion by 2050 (United Nations Development Programme, 2019).

This study focuses on how project managers can enhance their competence in managing the complexities of mega-infrastructure construction in Nigeria. With the country currently undertaking over 50 such projects valued at over $100 billion (Deloitte, 2021), this study explores how digitalisation can transform the methodologies of project managers operating in complex construction environments. The focus on Nigeria's infrastructure projects is supported by the prevalence of international construction conglomerates, which frequently require project managers to work in various regions (Raftery et al., 1998). This international context ensures that the findings have broad applicability, thus deepening our understanding of project management in complex megaprojects.

1.2 Research Rationale

Inadequate complexity management by project managers has been identified as a significant contributing factor to the underperformance of mega-infrastructure projects in terms of cost and timely delivery (Ma and Fu, 2020). The complexity arising from intricate interdependencies can present significant construction challenges (Ghaleb et al., 2022) and, if unmanaged, can directly jeopardise project success (Ma and Fu, 2020). Research attributes these suboptimal outcomes to the inadequacy of traditional strategies in developing critical competencies to handle emerging complexities (Remington and Pollack, 2016). Furthermore, the reliance of traditional strategies on static tools fails to help managers comprehend the dynamic complexities of mega-construction projects (Howell et al., 2010). Consequently, project managers lack effective solutions when faced with emerging complexities during construction (Salet et al., 2013), highlighting the inadequacies of prevailing strategies. This finding demonstrates the need for strategies tailored to the intricate demands of mega-infrastructure development.

Although traditional project management methodologies remain useful for smaller and less complex projects (Fewings and Henjewele, 2019), the challenges posed by construction complexity require nuanced approaches (Nyarirangwe and Babatunde, 2021). For instance, overreliance on predictability causes traditional strategies to underperform when addressing megaproject uncertainties (Söderlund et al., 2017). Specifically, traditional techniques often underestimate the multifaceted and dynamic uncertainties inherent in mega-construction (International Centre for Complex Project Management, 2012), such as when conventional scope decomposition strategies fall short because project scopes are ambiguous, typical with megaprojects (Fewings and Henjewele, 2019). Given the persistent inadequacies of prevailing strategies, a paradigm shift that employs tailored strategies suitable for the intricate demands of mega-infrastructure development is imperative for construction complexity management.

Construction complexity is the intricate challenge of overseeing large-scale infrastructure and civil engineering projects, arising from intricate interdependencies and interactions between diverse components and stakeholders across organisational and project boundaries (Kermanshachi et al., 2021). Successfully addressing complexity requires project managers to develop a holistic and nuanced understanding of its dimensions in terms of time and resource constraints (Qazi et al., 2016).

The complexity management research in this study was appropriately conducted to encompass both the behavioural and physical dimensions as outlined in the literature. Specifically, the behavioural dimension focuses on the competence traits of project managers. Identifying the prevailing competence factors relevant to each project type can enable managers to focus on nurturing them (Bashir et al., 2021). This targeted approach can potentially enhance competence in handling complexity. However, the complexity of developing competence highlights the necessity to explore project strategies that can aid managers in effectively navigating complex challenges.

Additionally, research has reinforced the crucial role of optimal competence in effectively managing complex construction projects (Mouchi et al., 2011). Multiple studies have also underscored a strong connection between technical competence and the successful management of project complexity (Dias et al., 2014). While competence encompasses the fusion of abilities, knowledge, skills, and experience (Moradi et al., 2019), the existing literature reveals persistent gaps in identifying the essential elements that foster competence development (Li et al., 2020).

Identifying requisite competence can be daunting, mainly because of the absence of a well-defined benchmark against which one can effectively measure and assess the attainment of optimal competence. The lack of a universally accepted standard exacerbates the difficulty in precisely delineating and evaluating competence across contexts. This underscores the limitations of relying solely on individual competence, highlighting the broader constraints within prevailing project management strategies and methodologies (International Centre for Complex Project Management, 2012). Consequently, it is essential to systematically investigate supportive project strategies, particularly given the inherent challenges of nurturing competence within constrained timelines.

Simultaneously, while addressing competence needs is crucial, a comprehensive understanding of complexity factors is equally pivotal for providing valuable contextual insights (Baccarini, 1996; Ghaleb et al., 2022). However, tackling the dynamic nature of complexity poses considerable challenges, making it difficult to comprehensively anticipate all pertinent factors (Kermanshachi et al., 2020). Moreover, limitations of the physical dimension in accounting for the impact of complexity and its constrained applicability to active complexity management in construction projects have been observed (Luo et al., 2017). Consequently, this study emphasises that enhancing management competence is a critical way for project managers to handle complexity dynamically, as it emerges during mega-construction.

Specifically, the literature demonstrates that competence factors such as communication, leadership, and cognitive abilities help project managers navigate complex challenges in developing countries (Li et al., 2020). Thus, developing competence represents a promising approach to enhancing project managers' capabilities in managing complexity. Nevertheless, the inherent challenges of systematically fostering competence within compressed timelines present substantial barriers (Sinha et al., 2006).

Given these challenges, mega infrastructure projects have tight timelines and budgets, constraining the systematic development of complex project management competencies (Fayek and Omar, 2016). Consequently, the shortcomings of traditional strategies to adequately address complexity have become evident. This realisation aligns with Remington and Pollack's (2016) view that innovative strategies are required to augment competence during project execution. Rather than solely adhering to developing competence as suggested by past research, it is imperative to adopt strategies that assist managers in effectively tackling the complex challenges presented by mega-construction projects.

Based on this perspective, this study also acknowledges the importance of identifying prevalent behavioural (Nyarirangwe and Babatunde, 2021) and physical factors (Dao et al., 2016) in assessing the efficacy of project strategies. This understanding is critical for assisting project managers to effectively address the multifaceted challenges that arise during infrastructure construction. Through a nuanced perspective of these multidimensional factors, tailored strategies can be formulated to manage the complexity inherent in mega-construction projects.

Considering the need for responsive strategies tailored to construction complexity, researchers have attempted to adopt strategies from other industries to improve infrastructure delivery. This recommendation stems from the revolutionary "Rethinking Construction Report" (Egan, 1998), which advocated that the construction industry benchmark best practices from other sectors to improve performance. Accordingly, researchers have attempted to apply strategies from manufacturing, information technology, business, and other fields to improve project delivery in construction, including lean construction (Koskela and Howell, 2002), concurrent engineering (Anumba et al., 2006), agile (Walker, 2015), and centralised programme management (Biesenthal and Wilden, 2014). However, these strategies have shown limited effectiveness in construction, owing to industry fragmentation, resistance to change, uniqueness of construction projects, and cross-project learning barriers. Given the unique and dynamic nature of construction projects, it is necessary to consider targeted frameworks, such as contingency theory (Howell et al., 2010), when adopting transferred practices.

The application of contingency theory in managing megaprojects has been found to be appropriate due to their dynamic complexities. Contingency theory posits that there is no single best approach to project management and that the optimal strategy depends on the unique context of each project (Donaldson, 2001). The use of flexible and situation-specific methods, as opposed to rigid traditional strategies, has been emphasised (Howell et al., 2010). This approach can effectively address the complexity of mega-infrastructure projects by leveraging digital construction and customisable project management tools. The strategic integration of digital technologies tailored to construction needs demonstrates the potential of addressing project complexity.

In line with contingency theory principles, leveraging digital construction and customisable project management approaches can effectively mitigate the complexity of mega-infrastructure projects. For instance, a combination of monitoring, scheduling, risk assessment, and communication tools creates an interconnected digital toolset tailored to assist project managers in managing complexity. Drawing parallel to the manufacturing industry, where the integration of digital systems substantially enhances managerial capabilities (Brettel et al., 2014), it is evident that a similar transformation can be achieved in the construction sector. The potential of digital construction to augment competence resonates strongly and offers a promising avenue for managing the intricacies of mega-infrastructure projects.

In line with contingency theory principles, the strategic integration of digital technologies tailored to construction needs demonstrates the potential to address project complexity. Digital construction offers significant opportunities to improve project delivery through heightened integration, safety, efficiency, and collaboration (Catlin et al., 2018). The foundation of this strategy lies in Building Information Modelling (BIM), which serves as a control layer that harmonises and facilitates the use of various other digital tools within the construction process. The project manager plays a crucial role in digitally transformed construction projects, enabling the real-time monitoring of operations, access to instant project updates, meticulous scheduling and estimation, risk evaluation, and seamless communication between the project and its stakeholders. Although these tools demonstrate potential, project managers' competence remains essential for their effective utilisation in complexity management. However, the intersection of digital capabilities, project manager competence, and complexity management remains underexplored, particularly concerning the potential of digital construction to enhance competence in complexity management.

This study addresses the current gap in understanding how project strategies can align with project manager competencies to navigate the intricate complexity dynamics within mega construction projects. The study provides insights into the interconnected relationships between digital construction, competence factors, and the multifaceted dimensions of complexity. These insights could equip project managers with adaptable strategies to address the evolving complexities. This study also introduces an innovative perspective to improve project delivery by establishing explicit connections between project strategies and competence enhancement. As the investigation progresses, it aims to make substantial theoretical and practical contributions to project management and complexity research, specifically in the context of the Nigerian construction industry. The following aim and objectives were formulated to investigate these phenomena in the context of mega-infrastructure projects in Nigeria.

1.3 Research Aim and Objectives

To address the complexities of mega-infrastructure projects and the limitations of prevailing strategies, this study investigates the potential impact of adopting digital construction to augment project managers' competence in managing complexity-induced challenges during mega-infrastructure construction in Nigeria. The following objectives were developed to robustly address the phenomena in the Nigerian context:

1. Evaluate the intensity and nature of crucial complexity elements during mega-infrastructure construction.
2. Identify the specific project manager competence factors that are most relevant and essential for effectively managing complexity during mega-infrastructure construction.
3. Explore the influence of digital construction on project managers' competence in comprehending and navigating complex realities during infrastructure construction.
4. Investigate the potential of digital construction in enhancing project management competence to address structural complexity during mega-infrastructure construction.
5. Determine the impact of digital construction on augmenting project managers' competence in managing the effects of dynamic complexity factors during mega-infrastructure construction.
6. Develop a conceptual framework for complexity management tailored to the context of mega-infrastructure construction in Nigeria.

1.4 Reseacrh Question

This section identifies areas that require further empirical investigation to support project managers in handling the complexity of efficient mega-construction delivery in Nigeria. It formulates research questions to guide the study in achieving research objectives. The need for adequate project strategies to enhance competence and mitigate complexity, a significant challenge (Remington and Pollack, 2016), is paramount. Competent managers are essential for handling complexity (International Centre for Complex Project Management 2012). However, Remington and Pollack (2016) argue that every manager can handle any project, with inadequate strategies posing the main challenges in complexity management. While extensive research has focused on the economic importance of mega-infrastructure, few studies have explored competence development in managing complexity (Luo et al., 2017). The broad research question investigates how digital construction can enhance competence in managing construction complexity, an unexplored area.

Research Question: Does adopting digital construction augment project managers' competence in containing complexity effects during mega-infrastructure construction?

The formulated research aims to support Nigerian project managers in handling complexity for efficient mega-construction, exploring complexity management from physical and behavioural dimensions. The broad research question aims to identify prevalent complexity elements and pertinent competencies, evaluating the efficacy of digital construction as a complexity management strategy.

Furthermore, in Section 1.2, we identified research streams supporting project managers in handling complexity for efficient mega-construction. This study explores these streams to identify prevalent factors reflecting project managers' context in dealing with mega-infrastructure complexity in Nigeria. The goal is to pinpoint relevant complexity elements and pertinent competence factors, evaluating the efficacy of digital construction as a complexity management strategy in the broad research question as discussed below.

1.4.1 Physical Complexity Management

Section 2.2 explores mega-construction complexity management from a physical perspective. Researchers have attempted classification and quantification based on emergent characteristics (Bilgin et al., 2022), project type, and location (Baccarini, 1996; Ghaleb et al., 2022). Dao et al. (2016) identified complexity elements by project type, developing adequate management strategies (Kermanshachi et al., 2021). Studies suggest complexity subjectivity based on project affiliation, necessitating more research from the project manager's perspective (Mikkelsen, 2021). No study has covered Nigeria's complexity by project type, location, and affiliation. Thus, the first sub-research question aims to identify the most prevalent mega-infrastructure construction complexity elements in Nigeria.

Sub-Research Question 1:What are the most prevalent complex elements that trigger challenges during infrastructure construction in Nigeria?

1.4.2 Behavioural Complexity Management

From the behavioural dimension, only competent project managers can handle complex projects (International Centre for Complex Project Management 2012). Identifying relevant competencies by project type and location would better position managers in managing complex trajectories during mega-construction. Dias et al. (2014) discovered a robust association between technical competence and complexity management, significantly enhancing performance. However, Abdou et al. (2016) emphasized that complexity can harm performance and underscore proactive management. Developing suitable competencies to complement complexity management strategies and enhance performance has been emphasized (Nyarirangwe and Babatunde, 2021). However, competencies for managing complexity in Nigerian mega-infrastructure projects must be identified. This study aims to address this gap, identify pertinent competencies, and explore how digital construction enhances managerial competence.

Sub-Research Question 2: What competencies are required by project managers to manage complexity during mega-construction projects in Nigeria?

These findings contribute to defining the study context in the proposed framework and support extensive research on project management competence development, emphasizing complexity management in developing countries. Moreover, the proposed questions illuminate the relationship between digital construction and project manager competence, specifically regarding complexity management in mega-infrastructure projects. The questions seek to uncover whether adopting digital construction practices enhances project manager abilities and skills, enabling effective complexity navigation and mitigation during construction in developing countries.

1.5 Research Scope

This study investigates methods for enhancing project management competence to effectively navigate the complexities of mega-infrastructure construction in Nigeria. The study focuses on project managers and companies registered with the Federation of Construction Industry (FOCI), an organisation that promotes excellence through best practices. A rigorous baseline was established to achieve the overarching objective of generating pathways for managers to improve mega-construction delivery through digitally augmented competences.

This study examined the use of digital technologies such as BIM, sensors, and automation by managers during construction projects, where complexity peaks. The research analysed the most prevalent complexity factors and competence needs identified through surveys of experienced FOCI registered managers to develop a tailored framework for enhancing competence in managing the identified complexities (Figure 2.5).

The research was built upon previous studies to identify the most prevalent complexity factors (Study α) and competence needs (Study β), relevant to Nigerian infrastructure projects through surveys of experienced FOCI-registered managers. The tailored framework specifically targets these complexities to improve project management competence in a country's mega-infrastructure construction projects.

Overall, this timely undertaking contributes to elucidating the pathways for digitally enhanced competence amid complexity, by building a localised yet replicable knowledge base to inform sophisticated construction practices tailored to developing world realities.

1.6 Contribution to Knowledge

Previous research offers numerous recommendations to the construction industry regarding techniques for helping project managers enhance their competence in complexity management. However, despite many recommendations, project managers cannot manage the inherent complexity of mega-infrastructure construction. The current study hypothesised that benchmarking digital strategy from manufacturing could be cogent in enabling managers to oversee complexity trajectories during construction. The study proved the theorised argument and showed that digital construction could enable managers to handle infrastructure complexity during mega infrastructure construction in Nigeria. ***Notably, this study suggests that digital construction may offer potential solutions to challenges posed by complexity in mega-infrastructure construction, contributing to existing knowledge.***

This study conducted a comprehensive investigation into the potential of digital construction involving the integrated application of digital technologies to enhance project management competence in executing large-scale infrastructure projects in Nigeria. Despite numerous recommendations over the decades, project managers face challenges in effectively managing the intricate dynamics of complexity during mega-construction. However, this compartmentalised approach has proven insufficient, as project managers still struggle to deliver projects successfully amidst multifaceted complexities.

This study proposes a more comprehensive perspective recognising the interconnected relationships between complexity factors, competence requirements, and project strategies. Rather than studying these concepts in silos, there is a need to strategically integrate them concurrently within a comprehensive framework to enhance project performance effectively. Accordingly, this study introduces an innovative synergistic lens by investigating whether the strategic implementation of digital construction can augment critical competencies to address the prevalent complexities of mega-construction. This integrated enquiry consolidates multiple factors, including complexity, competence, and strategy, and focuses on enhancing performance, while acknowledging the contingent nature of the relationship.

Additionally, this study produced robust and original evidence by conducting rigorous empirical analysis using a mixed-methods approach that included surveys, interviews, and observations. This evidence demonstrates that integrating suitable digital tools can significantly bolster project management capabilities in crucial areas such as communication, planning, and coordination. Consequently, managers can gain unprecedented control over the intricate structural and dynamic complexities arising from uncertainties, interdependencies, and scales. ***Hence, this study makes a seminal contribution by confirming the viability of human-centred digital construction as an approach to enhance project management competence tailored to the unique context of Nigeria's developing construction industry***. More specifically, it builds upon the momentum of adopting building information modelling by highlighting the potential of synergistically integrating appropriate digital technologies in contextually relevant combinations. This ground-breaking discovery provides practitioners valuable insights into leveraging digital tools to enhance mega-construction delivery through improved team collaboration, information sharing, visualisation, and real-time oversight.

Furthermore, this research introduces an original methodological contribution by categorising complexity factors based on their emerging intensity. The meticulous identification of the most significant structural and dynamic complexities prevalent in Nigerian infrastructure projects offers a crucial empirical foundation for studying the impact of digital tools. This diligent analysis of complexity also enhances both scholarly and industrial understandings of the complex patterns present in Nigerian construction projects. Simultaneously, it outlines the need for competence development, establishing vital groundwork for devising aligned strategies. The developed conceptual framework offers localised guidance for effectively navigating project intricacies by implementing digitally enhanced skills.

From a practical standpoint, the insights generated shed light on promising avenues for project management to incorporate the advancements of Industry 4.0 by configuring and implementing contextually relevant, human-centred digital tools. In terms of education within the construction sector, this study suggests integrating knowledge of digital construction to equip future managers with essential capabilities as the utilisation of digital technology continues to expand.

This study offers an original and multifaceted contribution by demonstrating the potential of digital construction in enhancing project management competence in the face of complexity. Thus, it establishes a crucial foundation for advancing the theory and practice of project management in Nigeria's rapidly growing but under-researched context. This is achieved by strategically applying human-centred digital augmentation to managerial abilities.

1.7 Thesis Structure

This doctoral thesis, which encompasses the original research undertaken, is structured systematically into nine core chapters that rigorously investigate the potential of digital construction to enhance project management competence in the context of Nigeria's contemporary mega-infrastructure initiatives. Figure 1.1 illustrates the chapters and stages of this study, as discussed in this section.

Chapter One presents a comprehensive introduction to the research, establishing a solid foundation and focusing on the overall direction of the PhD undertaking. It outlines pertinent details regarding the background, problem statement, current gap in knowledge, research aim and objectives, specific research questions, underlying rationale, and expected original contributions. Thus, it provides the reader with essential preliminaries regarding the genesis, purpose, significance, and envisioned contributions of this systematic research.

Chapter Two undertakes an extensive review of scholarly literature encompassing the core domains of project complexity, project management competence, and cutting-edge digital technologies for complexity management. This critical synthesis of more than 90 seminal sources provided a vital knowledge platform for the structured development of the original conceptual framework proposed in this study.

Chapter Three offers a detailed elucidation of the pragmatic mixed-methods research methodology adopted over multiple phases to address the aim and objectives. It provides specifics regarding the data collection instruments and approaches employed through surveys, interviews, non-participative observations, and expert validation. Additionally, it delineates the techniques used to analyse the collated data. This provided the reader with a comprehensive methodological perspective.

Chapter Four reports the statistically analysed results of the exploratory factor analysis conducted to determine the intensity categorisation of key complexity factors within the contextual setting of Nigerian mega-infrastructure projects (referred to as Study α).

Chapter Five outlines insightful results from the narrative analysis of qualitative data gathered through semi-structured interviews with experienced construction project management professionals. This encapsulates their perspectives on the most critical competence factors for mega-infrastructure projects in the Nigerian context (Study β).

Chapter Six provides revelatory qualitative insights assimilated from the non-participative observation of project managers leveraging digital technologies across nine active mega-construction project sites in Nigeria (Study γ).

Chapter Seven presents a comprehensive exposition of the statistically analysed quantitative survey findings regarding the influence of adopting digital construction on augmenting multidimensional project management competence factors when executing mega-infrastructure projects.

Chapter Eight offers a detailed and logically structured discussion that interprets the overall empirical results that emerged through the mixed-methods approach. It analyses the findings concerning existing scholarly literature to synthesise coherent explanations and perspectives.

Finally, **Chapter Nine** concisely outlines the original contributions to the knowledge achieved through this doctoral research along with the limitations and recommendations for future scholarly efforts that can build on the work accomplished here.

In summary, the systematic structuring into nine core chapters provides a logical progression that guides the reader through the multi-year research process from conceptualisation to conclusions.

It delineates the origins, objectives, systematic approach, empirical findings, and envisioned future directions of this original PhD study, focusing on furthering construction project management through strategic human-centred digital augmentation.

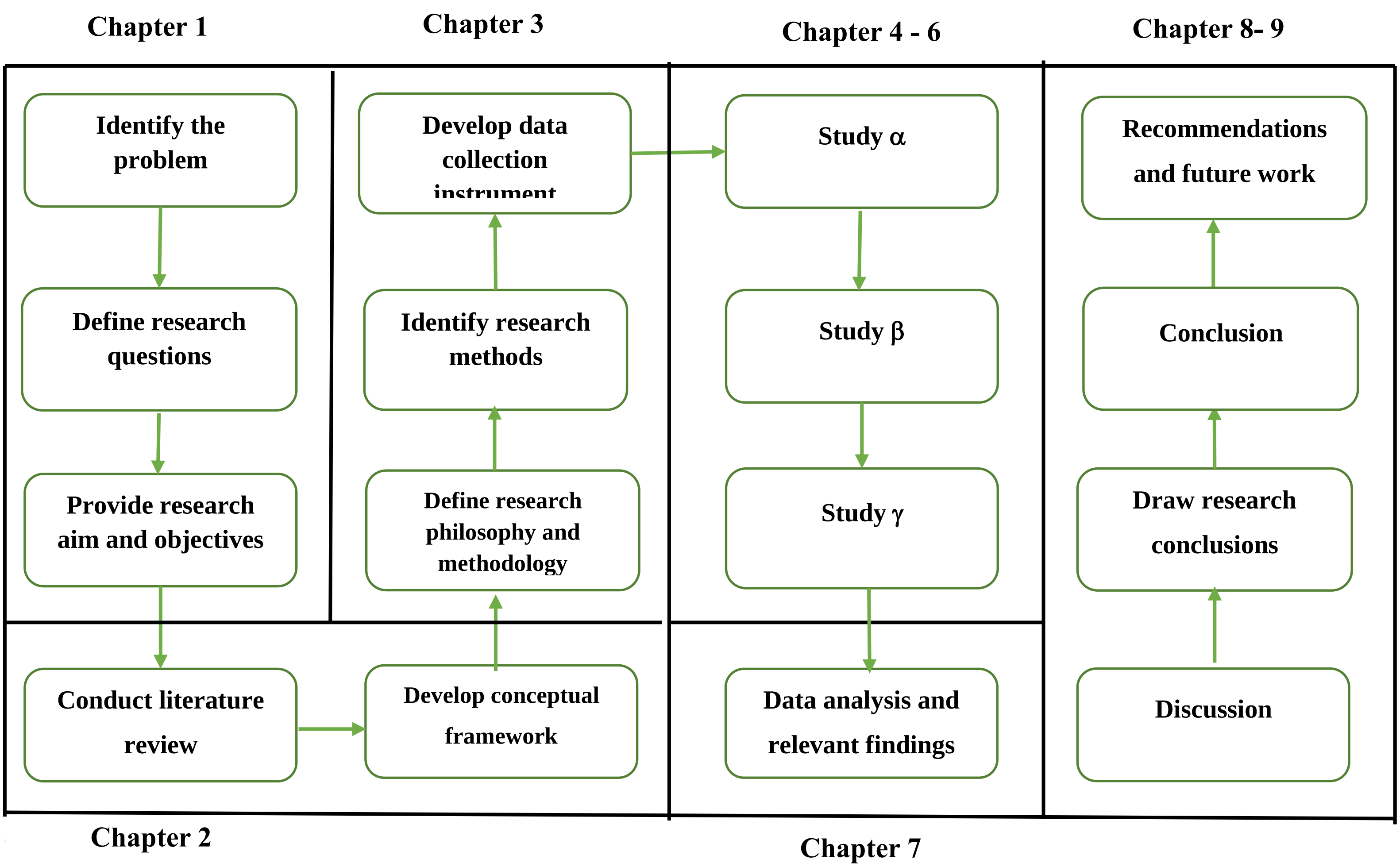

Figure 1.1 Thesis structure.

Summary

Chapter 1 introduces the background, rationale, research gap, aim, objectives and projected contributions of this doctoral study, focusing on leveraging digital construction to enhance project management competence amidst the complexity of Nigerian mega-infrastructure projects. This establishes the critical yet underperforming role of megaprojects and the need for innovative approaches tailored to inherent construction complexities. The limitations of the prevailing project management strategies were synthesised. This highlights the untapped potential of strategic digital construction inspired by manufacturing sector digitalisation. This study aims to make significant theoretical and practical contributions by demonstrating how human-centred digital strategies can be leveraged to enhance competence in addressing multifaceted construction challenges. Chapter 1 presents the background and direction of this research to progress project management in Nigeria's developmental context. Building on this foundation, the next chapter presents a comprehensive review of the scholarly literature encompassing the core domains of project complexity, competence, and digital technologies.

Chapter 2 Literature Review

This chapter comprehensively synthesises over 90 seminal sources across the core domains of project complexity, competence, and digital construction. This critical review established a rigorous scholarly foundation for the original conceptual framework proposed in this study. First, this chapter explores the prevalence of complexity-induced underperformance in mega-infrastructure projects, probing the limitations of prevailing strategies and knowledge gaps. It then elucidates the multifaceted dimensions of mega-construction complexity, emphasising structural and dynamic complexity as pivotal constructs that require targeted competence. Subsequently, diverse technical competencies identified as vital for complexity management were analysed. Furthermore, the chapter discusses traditional strategy constraints, pointing to the untapped potential of digital construction inspired by manufacturing principles and contingency theory. This chapter integrates insights from seminal sources, identifies research questions, and proposes a conceptual framework that leverages human-centred digital construction to enhance competence in megaproject complexity management.

2.1 Mega Infrastructure Performance

The escalating complexity of mega-infrastructure projects, their unique nature, and the unrelenting stakeholder demand for enhanced performance in the construction industry substantially contribute to the pervasive subjectivity and ambiguity in defining project success (Diallo and Thuillier, 2005). Cooke-Davies (2002) posited that optimal performance is a predictive indicator of success in expansive construction undertakings and is influenced by various contextual success determinants that profoundly impact performance. Consequently, consistently attaining satisfactory project performance is indispensable for successful project outcomes. However, Baker et al. (1988) asserted that realising absolute project success remains a largely elusive endeavour because of the fundamentally divergent interpretations of diverse project participants. For instance, for a structural engineer, success is manifested predominantly through structural stability, whereas for a project manager, it entails achieving the challenging trifecta of time, cost, and quality (Collins and Baccarini, 2004). Conversely, clients may perceive success as receiving maximum value for their investment. Hence, the essential definition of project success is an abstract and fluid conceptual construct contingent on subjective interpretations and temporal contextual factors (Zavadskas et al., 2014).

The fundamental notion of project success continues to be the subject of extensive debate and disagreement among stakeholders in the industry, driven pervasively by its inherent subjectivity, which fluctuates substantially based on the degree of individual engagement and perspectives on the project (Khan and Rasheed, 2015). Turner et al. (2013) rightfully emphasise that the varied, inconsistent definitions of project success propagated within different project management schools of thought can readily engender disparate, conflicting perceptions, particularly in expansive, intricate infrastructure projects. Currently, three primary disjointed perspectives are predominant concerning the success of megaprojects. The first, proposed by the European Union Cost Action, hinges rigidly on empirically determining project success solely by following the conventional iron triangle paradigm. The second perspective, advocated by the OMEGA Centre of Megaprojects, posits that success is entirely contingent on context and inevitably evolves throughout the project's lifecycle. Finally, the NETLIPSE network asserts that cultural, political, legal, and national factors profoundly influence success (Patmore, 2016).

A prime example that highlights the prevalence of conflicting viewpoints on project success is the extensive Big Dig Boston Tunnel Project. Despite exceeding its initial budget of $2.56 billion and culminating in a profoundly escalated cost of $14.7 billion, along with an eight-year delay in completion, the project fell remarkably short of adhering to the iron triangle rule (Greiman, 2010). However, despite egregious time and cost overruns, the project was broadly aligned with and fulfilled the client and end users' business expectations. Upon finalisation, it conclusively led to a substantial reduction in travel time along the Boston Central Artery Road and a one-third enhancement in the overall quality of life (Greiman, 2010).

The examination of performance in extensive infrastructure projects spans various professional perspectives, including economic facets, governance and stakeholder management, construction and site administration, intricate project management, planning, surveillance, control, and procurement (Hu et al., 2013). Despite these concerted endeavours, megaprojects persistently and profoundly underperform globally. The 2015 Global Construction Survey conducted by KPMG revealed that more than half of all surveyed global construction firms encountered at least one major underperforming mega-infrastructure project in 2014 alone (KPMG, 2015). A subsequent survey conducted in 2017 painted an equally disconcerted, bleak panorama. Among over 200 senior construction executives, 25% expressed confidence in the industry's fundamental capability to execute megaprojects consistently within the original budget and schedule (KPMG, 2017).

This alarming data underscores the global endemic crisis of underperformance in megaproject delivery. The worldwide construction sector lacks the requisite strategies, tools, and managerial competence to execute large-scale complex initiatives successfully. The escalating scale, complexity, and stakeholder expectations of megaprojects in the 21st century intensify this endemic underperformance. The industry urgently needs transformational solutions to address the deeply entrenched factors undermining megaproject outcomes (Müller and Jugdev, 2012).

This study delves into this pressing concern by examining the potential role of digital construction in assisting project managers in navigating complexity, thus ensuring punctual and budget-compliant delivery of extensive infrastructure projects. Accomplishing this goal would signify a stride towards fortifying the economic advancement of nations such as Nigeria. As these countries progressively host large-scale infrastructure ventures, the potential advantages of enhanced project management and execution are manifold, extending beyond economic advancement to encompass societal progress and environmental sustainability.

2.2 Complexity during Infrastructure Construction

Tough problems usually don't get solved peacefully. Either they don't get solved at all – they get stuck – or they get solved by force. – Adam Kahane

The inherent complexity of mega-infrastructure projects is unequivocal, arising profoundly from their massive physical scale, vast scope, multitude of interdependent components and tasks, and endemic presence of extensive uncertainty due to elongated project timeframes, perpetual scope changes, and heightened political interest (Siemiatycki, 2015). The fundamental subjectivity of complexity makes it an exceptionally challenging concept to comprehensively define and describe with precision, leading to a multiplicity of widely divergent perspectives within scholarly literature (Luo et al., 2017). Baccarini (1996), one of the earliest seminal contributors to this discourse, vaguely characterised complexity as "consisting of many varied interrelated parts," further breaking it down into the concepts of differentiation and interdependency. The former refers to the number of diverse components encompassed within a project, such as tasks, specialists, subsystems, and constituent elements, whereas the latter denotes the intricate degree of dynamic interaction between these heterogeneous components (Gidado, 1996).

However, Luo et al. (2017) offered a marginally broader definition, abstractly describing complexity as the complex interaction among distinct and parallel elements that are structural, dynamic, and fundamentally uncertain. They further asserted that this complexity, albeit poorly understood, correlates with perceived project difficulty and risk (Dao et al., 2017). Meanwhile, Girmscheid and Brockmann (2008) attempted to delineate mega infrastructure project complexity in a similarly vague manner as "a set of problems that consists of many parts with a multitude of possible interrelations, most of which are of high consequence in the decision-making process that brings about the final result." Additionally, Damayanti et al. (2021), viewing complexity from the limited perspective of project managers in developing countries, define it somewhat narrowly and deterministically as an obstacle that negatively and inevitably impacts project performance.

Table 2.1 Project Complexity Definitions

S/No	Author (Year)	Definitions
1	Pich et al. (2002)	Complexity is the inadequacy of information when too many variables interact.
2	Geraldi and Adlbrecht (2008)	Projects in a complex environment.
3	Vidal et al. (2011)	Complexity is the property of a project that makes it difficult to understand, foresee, and control its overall behaviour, even when given complete information about the project system.
4	Kermanshachi et al. (2020)	Project complexity is the degree of interrelatedness between project attributes and interfaces and their consequential impact on predictability and functionality.
5	Bilgin et al. (2022)	Project property that stems from the interaction of project features, uncertain variables/conditions, and managerial actions forming a pattern, which emerges over time

Despite these disparate academic attempts at definition, practitioners in the field often describe complexity impressionistically using vague colloquial terms such as difficult, complicated, knotty, unique, unclear, and intricate (Whitty and Maylor, 2009). Daniel and Daniel (2018) underscored the absence of a universally accepted scholarly term to comprehensively describe and measure complex engineering projects and the multidimensional nature of project complexity, thereby perpetuating extensive fundamental disagreement and debate within the project management sphere. Bakhshi et al. (2016) further explicated how the inherently challenging task of developing an integrated, mathematically robust definition of project complexity, encompassing its numerous characteristics and dimensions, has inadvertently led to substantial inconsistencies in its practical usage and application.

Understanding complexity is frequently categorised into descriptive and perceived classifications (Schlindwein and Ison, 2004). Descriptive complexity is considered an intrinsic quantitative characteristic of a system, leading researchers to attempt to classify and quantify complexity based on predetermined indicators. By contrast, perceived complexity is an impressionistic qualitative concept defined subjectively by individual experiences and perspectives. While this study aligns more closely with the latter perspective, it describes complexity as uncertainty and task difficulty dynamically emerging from diverse project characteristics and participant interactions, fundamentally hindering project managers from performing optimally during mega-infrastructure construction initiatives.

Nguyen et al. (2018) extensively underscored the criticality of proactively managing multifaceted complexity in determining profit margins, schedule adherence, and stakeholder satisfaction during mega-infrastructure projects, highlighting the pivotal need for substantially more rigorous research in this crucial area. Chapman (2016) further argues that complexity is most pervasively and chaotically manifested at the project execution phase on the active construction site. Therefore, a sophisticated understanding of the emergent patterns of complexity at this level could enable project teams to mitigate the most adverse effects and radically improve their overall performance during infrastructure development. This study explores project complexity and its multiple co-evolving dimensions to elucidate its intrinsic characteristics during mega-construction delivery and defines a targeted scope for developing enhanced management strategies.

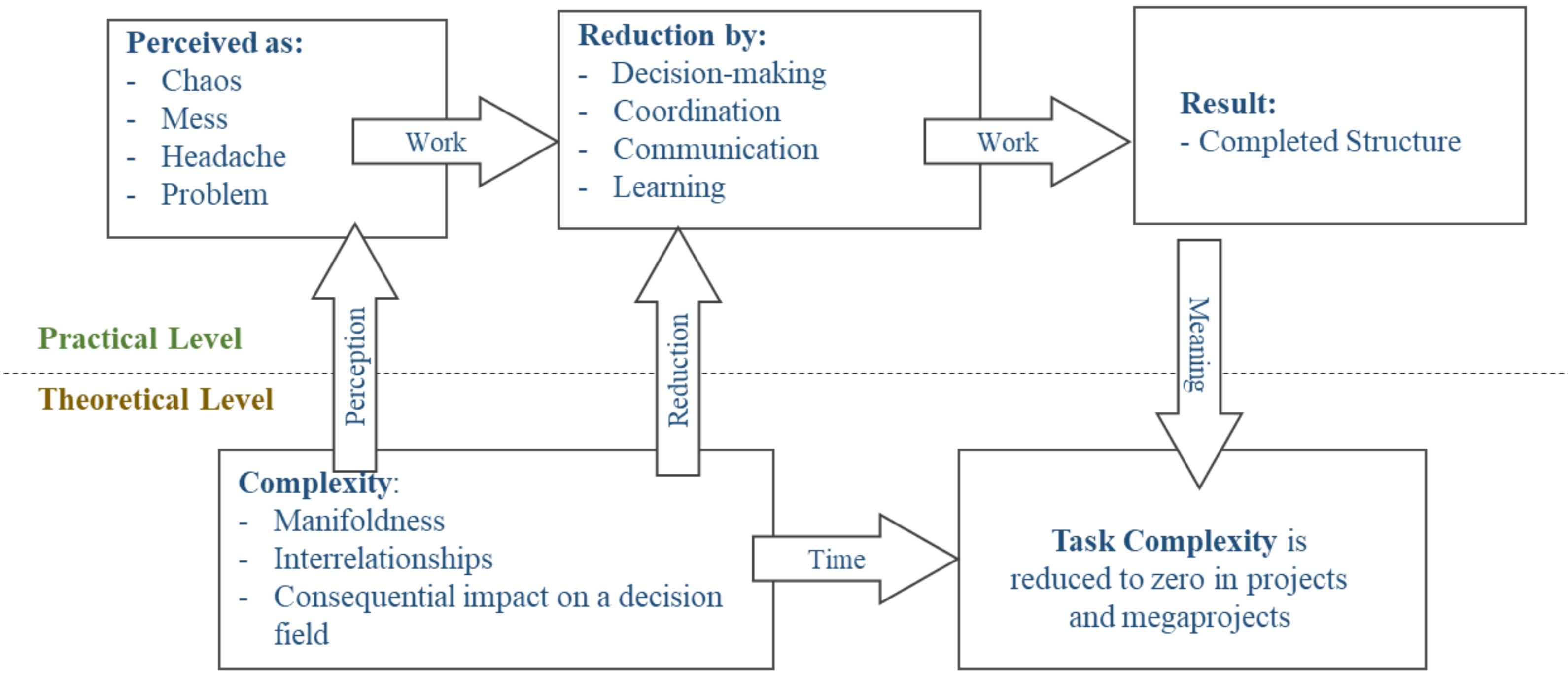

Figure 2.1 Complexity as a Practical and Theoretical Construct of Mega Infrastructure Projects (Adapted from (Girmscheid and Brockmann, 2008)

2.2.1 Dimensions/Types of Complexity in Construction

Extensive research spanning several years has explored the fundamentally multifaceted nature of infrastructure project complexity; however, a unanimous overarching definition remains elusive among scholars in this field (Ghaleb et al., 2022). One persistent scholarly strand has concentrated narrowly on taxonomically compartmentalising the theoretical dimensions of complexity under the optimistic assumption that such categorical understanding could empower project managers to enact appropriate tactical decisions and strategic planning during project conceptualisation. The pioneering study by Gidado (1996) simplified complexity into two broad groups: intrinsic task elements encompassing opaque factors, such as task difficulty and technical complexity, and essential components related to workflow configuration, such as sequence rigidity and construction element interdependency.

Other researchers, such as Girmscheid and Brockmann (2008), employed the grounded theory approach to classify project complexity in large-scale engineering projects into overall, task, social, and cultural complexity. Task complexity, described as work density, can be better managed through strategic decision-making and coordination (Figure 2.1). Lessard et al. (2014) developed a theoretical framework for grasping the nuances of infrastructure complexity, identifying project properties and features, such as difficulty, non-linearity, outcome variability, and non-governability, as integral to complexity. Their work highlighted two dimensions of complexity: technical and institutional.

Subsequent studies have used different approaches to complexity. For instance, Nguyen et al. (2015) identified six dimensions of complexity in a transport project using a fuzzy analytic hierarchy process. The dimensions are organisational complexity, technological complexity, environmental complexity, socio-political complexity, infrastructure complexity, and scope complexity. The study proposes a complexity-level measure to enable project managers to evaluate and quantify complexity.

Kermanshachi and Safapour (2019) comprehensively categorised the complexity attributes of construction projects. Kardes et al. (2013) postulated that indicators of complexity are multifaceted, encapsulating aspects such as stakeholder management, governance, fiscal planning, quality, legal aspects, interfaces, execution targets, design and technology, location, scope definition, and project resources. This exhaustive classification underscores the complexity inherent in construction projects, suggesting that a practical management approach requires broad consideration of various interconnected dimensions (Haga and Marold, 2004).

Simultaneously, Mirza and Ehsan (2017) offered a more precise categorisation of complexity factors centred on scheduling constraints during infrastructure development. They identify six core factors: time, scope, cost, quality, resources, and risk complexity. This conceptualisation provides a time-bound perspective on project complexity, emphasising the significance of schedule constraints and the need to manage them effectively for successful project implementation.

In addition to these discourses, Bilgin et al. (2022) provided a distinct perspective by exploring complexity patterns from the standpoint of construction practitioners. Their study centres on the experiential insights of those actively involved in construction processes, highlighting the salience of project characteristics, size, novelty, and strategic importance as crucial determinants of construction complexity (Dao et al., 2017). Müller and Turner (2007b) categorised project complexity in infrastructure projects as low, medium, or high complexity. On the other hand, Remington and Pollack (2016) proposed a four-dimensional framework to understand the factors influencing complexity. These dimensions include structural, technical, directional, and temporal complexity. As Remington and Pollack (2016) described, technical complexity refers to the interconnections between multiple independent solution options. Directional complexity involves ambiguity arising from various interpretations of the project scope, objectives, and goals. The structural complexity pertains to the challenge of tracking multiple interconnected tasks. Temporal complexity encompasses the uncertainty surrounding the possibility of unplanned changes (Remington and Pollack, 2016).

The body of research conducted by the researchers mentioned above and other scholars in the field have made significant contributions to the understanding of the complexity of project management. Their work has expanded our knowledge and provided various perspectives on categorising and comprehending complexity. However, there has been a notable shift in research focus in recent years due to influential studies by Maylor et al. (2008) and Vidal et al. (2011). These studies highlighted the importance of understanding and assessing the complexity of effective management practices. Their findings emphasised the need to consider complexity, particularly uncertainty-induced factors, during the planning stage of projects. Consequently, there has been a surge in the development of complexity models and frameworks in the research landscape. These models and frameworks aim to capture the intricate nature of complexity and guide project planning management.

Researchers such as Lebcir and Choudrie (2011), Xia and Chan (2012), Bosch-Rekveldt et al. (2011), and Lu et al. (2015) have proposed unique models to address different facets of complexity (Padalkar and Gopinath, 2016). In this regard, Lebcir and Choudrie (2011) developed a complexity framework by employing a dynamic simulation model to investigate the impact of complexity factors on construction project cycle time. Their findings suggest that project uncertainty, infrastructure newness, connectivity, and size are major drivers of complexity. Xia and Chan (2012), in their study using a three-round Delphi questionnaire survey, proposed a complexity index for large building project planning and implementation in China. The survey identified construction method, project size and scale, project schedule urgency, immediate locality, and geological conditions as critical sources of complexity for large building projects.

Bosch-Rekveldt et al. (2011) developed a framework to appraise the complexity of large engineering projects during the planning phase and align the project with its inherent complexity.

The framework, based on the technical, Organisational, and environmental (TOE) framework, identifies complexity elements, such as the degree of definition, scope development, contract form, number of different disciplines and cultures, project duration, scheduling, project size, project budget, and the impact of dynamic changes. Lu et al. (2015) developed a complexity measurement model to improve the management of tasks and organisational complexity during large-scale construction.

Chapman (2016) went a step further to examine the dimensions and characteristics of complexity that could aid decision-making on rail megaprojects. The study identified six dimensions of complexity, categorised into those under project control (management, delivery, and task) and those outside its control (finance, site location, and context). In addition, more emphasis was placed on the aspect of complexity under project control, as this determines megaproject performance and the overall achievement of the objective (Chapman, 2016). Maylor and Turner (2017) built on the previous work of Geraldi et al. (2011) to suggest reducing project complexity by matching projects with competent managers. The study demonstrated how to reduce complexity by potentially matching each with a competent manager who best fits the project. This study classified complexity into structural, emergent, and socio-political, with each pseudonym for uncertainty and dynamic complexity (Maylor and Turner, 2017).

Vidal et al. (2011) described complexity as a property of a project that renders it difficult to understand, predict, and foresee even with sufficient information. They proposed a decision-making framework for project managers using the Analytic Hierarchy Process, highlighting factors such as project size, variety, interdependence, and context dependence (

Figure 2.2). Dao et al. (2016) adopted a constructive approach to examine and assess complexity, surveying companies in the construction industry. They identified factors, such as physical location, project size, level of control, clarity of scope, and interface, as influential factors in infrastructure projects. Nikolić and Cerić (2022) examined the complexity of construction projects from a contractor's viewpoint. The findings highlight multiple dimensions of complexity, including scheduling, planning, resources, scope changes, and stakeholder management. This study proposes a classification framework to categorise these complexity elements and provides a structured approach for managing complexity.

Luo et al. (2020) proposed a project complexity measurement method using causal relationships to assess complexity under various what-if scenarios. They incorporated factors from the existing literature to guide model development, as deployed in the current study, to identify the complexity elements present during mega construction in Nigeria. Kian Manesh Rad et al. (2017) developed a complexity assessment model for energy megaprojects using a Delphi-Analytical Hierarchy Process for group decision-making. Their model classified complexity as external or internal with a grading system to rank complexity indicators. Other researchers, such as Dao et al. (2016), He et al. (2015), Kermanshachi et al. (2020), and Vidal et al. (2011), developed novel frameworks based on the analytic hierarchy process (AHP) for project complexity measurement during construction.

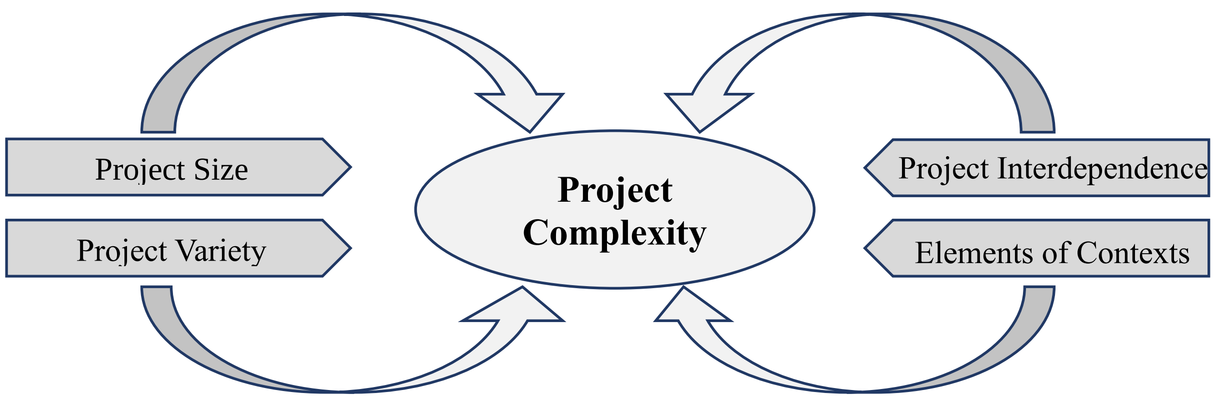

Figure 2.2 Drivers of Project Complexity (adopted from Vidal and Marle (2008))

Building upon these studies, it can be argued that the complexity of mega-infrastructure projects can be categorised into factors under the project's control and those outside its control, based on Kian Manesh Rad et al. (2017) taxonomy. This classification aligns with the project management view of complexity, which includes structural complexity, uncertainty within the project, and socio-political elements outside the project (Bakhshi et al., 2016). However, this study focuses on the complexity emerging within the project construction site, reflecting the project manager's sphere of responsibility.

Past research has frequently examined project complexity across the entire lifecycle, often overlooking the distinct intricacies that manifest during specific phases. A more advantageous approach involves investigating stages, particularly the developmental phase, in which complexity peaks with severe ramifications. Delving into targeted phases enables a more profound analysis of emergent intricacies, fostering tailored strategies to address inherent challenges. Thus, this study focuses on the complexities arising within construction sites that fall under the jurisdiction of project managers (Chapman, 2016). The project manager is responsible for managing internal complexity, whereas external complexity, encompassing socio-political elements, is typically overseen by the project director, particularly in the case of megaprojects.

Accordingly, this study examines structural and dynamic complexity, acknowledged as pivotal in mega-construction (Brady and Davies, 2014). Studies maintain narrow scopes by analysing just one dimension, which can impede comprehension of the emergent characteristics and management of complexity (Luo et al., 2017). By contrast, this study adopts a comprehensive approach by exploring both structural and dynamic facets to gain more profound insights into construction complexity and inform strategies to enhance project outcomes. Additionally, past research has occasionally conflated uncertainty and dynamic complexity despite their interconnected relationship with change. To ensure precision, 'dynamic complexity' encompasses both concepts (Maylor and Turner, 2017). This study aims to understand the intricate factors that contribute to the complexity of construction projects by closely examining the various aspects of complexity. In the subsequent section, the study explores the intricate relationship between structural and dynamic complexity and how they relate to this investigation.

2.2.2 Structural Complexity and Dynamic Complexity

Research has frequently conflated the notion of structural and dynamic complexity when examining the multifaceted dimensions of complexity in mega-infrastructure projects (Ghaleb et al., 2022). However, this study treats these two concepts as distinct entities, each contributing uniquely to the overall project complexity. Structural complexity, which has garnered substantial attention in the academic literature on infrastructure initiatives, pertains to the scale of structural components, the number of discrete project elements, and the intricate interplay among these components and elements. Dynamic complexity, in contrast, refers to the spontaneous changes that materialise because of the evolving relationships and interactions between project components over time. Essentially, it encapsulates the inherent uncertainty across the project lifecycle (Davies and Mackenzie, 2014).

Elaborating specifically on dynamic complexity, Davies and Mackenzie (2014) delineated this concept as an ongoing process of transformational change unfolding within individual system components and their broader environment. This change often engenders significant rework and disorder when misconstrued by project managers. Maylor and Turner (2017) built upon this dichotomy, explicating that while structural complexity represents established factors within the project timeline, dynamic complexity grapples largely with unknown or unpredictable elements.

Williams (1999) employed Baccarini's (1996) seminal definition of structural complexity, shedding light on its multiple influencing factors. These encompass task diversity, interdependence between discrete tasks and teams, and the extent of operational interdependency among a project's organisational components. Davies and Mackenzie (2014) subsequently refined the conceptualisation of structural complexity by linking it to "the arrangement of components and subsystems into an overall system architecture"–an alignment reflecting systems of systems thinking. In their exploration of complexity dimensions, they identified several critical factors, including stakeholder hierarchy, interdependence, integration, and the overarching hierarchy of the system.

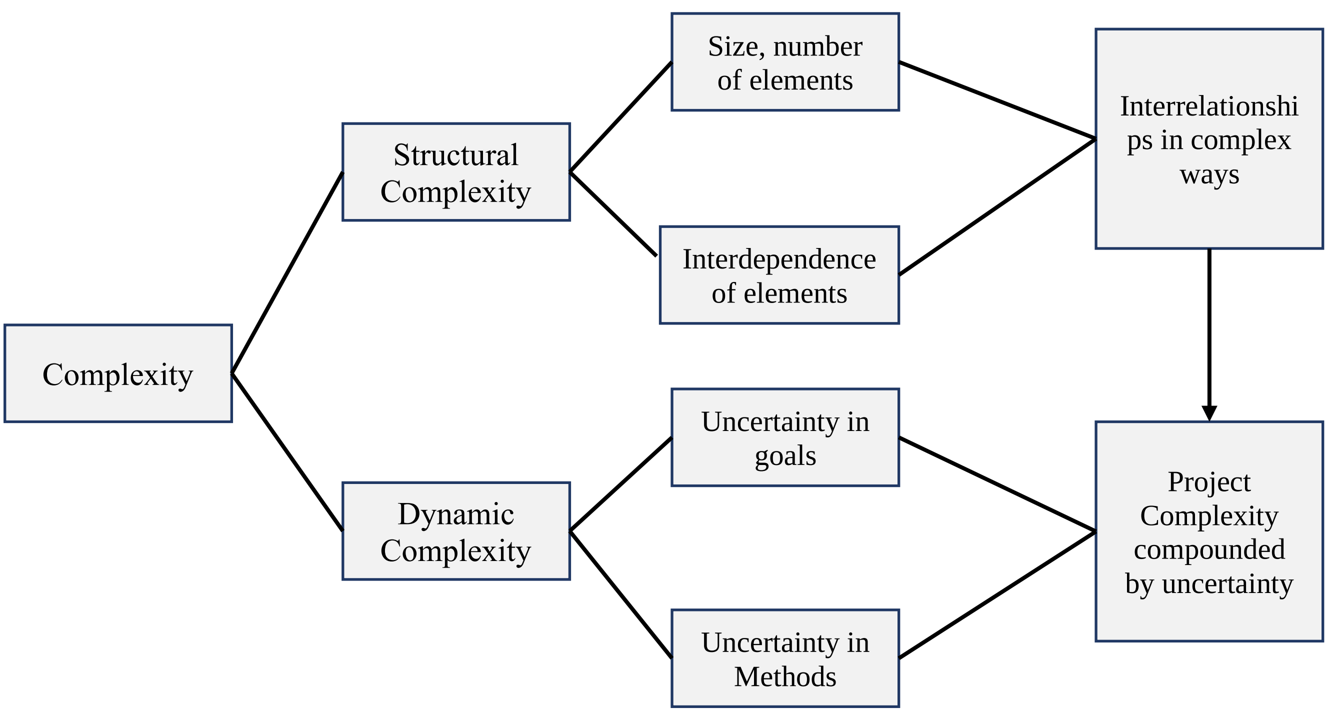

Figure 2.3 Project Complexity Construct (adopted and modified from Williams (1999)

In their study of project complexity patterns, Geraldi and Adlbrecht (2008) elucidated multiple facets of structural complexity, which they categorised based on fact, faith, and interaction. In fact, grounded factors included quantifiable elements such as project size and interdepartmental dependencies, while faith-based factors encompassed intangibles such as low maturity levels and innovative technology introduction. Interaction-related facets reflect a project's socio-political underpinnings. Building on this, Bilgin et al. (2022) highlighted that discernible complexity patterns materialise from the confluence of structural and dynamic complexity traits. To facilitate the classification of the intensity level of projects, Whitty and Maylor (2009) devised a Structural Dynamic Interaction (SDI) matrix that delineates projects on a scale from Level 1 (relatively straightforward to manage) to Level 4 (extremely complex) (Figure 2.4).

Structural	1. Independent structural complexity	2. Interacting structural complexity
Dynamic	3. Independent dynamic complexity	4. Interacting dynamic complexity

Figure 2.4. Structural Dynamic Interaction (SDI) matrix

Scholars have also highlighted various factors that can catalyse the complexity of construction projects. Akintoye (2000) posited that project characteristics such as type, site constraints, construction methods, and design complexity could act as catalysts for project complexity. Bosch-Rekveldt et al. (2011) identified size, resources, project teams, risk, scope, tasks, experience, and location as the complexity factors. He et al. (2015) highlighted the project type, overlapping of design and construction work, limited resources, complicated communication modality, task complexity, and dependency on operations. Nguyen et al. (2015) identified climate conditions, environmental risk, scope ambiguity, and project size as factors exacerbating the complexity of mega-infrastructure projects. Chapman (2016) explored complex indicators on infrastructure projects and classified each into three categories - the delivery team (who), delivery process (how), and project characteristics (what). The 'who' factors are the disciplines and resources; the 'how' factors are information, task, time, tools, and methods; and the 'what' are the objectives and technical traits. Recognising the unique characteristics of each project type (Bilgin et al., 2022) and the peculiarities of their respective geographical locations (Sinha et al., 2006), Study α identified the most pertinent factors from Table 2.2 for the current study setting, allowing for an effective scope definition.

Table 2.2 Construction Complexity Elements

Structural Complexity Dimension			
Constructs	**Description**	**Elements**	**Source**
Size	The project's physical attributes in terms of height and density.	Size	(Jarkas, 2017; Lebcir and Choudrie, 2011; Xia and Chan, 2012)
		Structure type	(Lebcir and Choudrie, 2011; Xia and Chan, 2012; Baccarini, 1996)
		Site area	(Lebcir and Choudrie, 2011; Xia and Chan, 2012; Dao et al., 2017; Mirza and Ehsan, 2017; Gajić and Palčič, 2019; Geraldi and Adlbrecht, 2008; Bosch-Rekveldt et al., 2011; Chapman, 2016)
		Density	(Xia and Chan, 2012; Dao et al., 2017; Lebcir and Choudrie, 2011)
		Number of elements	(Gidado, 1996; Lebcir and Choudrie, 2011; Mirza and Ehsan, 2017; Ahn et al., 2017)
		Number of participants	(Dao et al., 2017; Kermanshachi et al., 2018; Mirza and Ehsan, 2017; Baccarini, 1996; Kermanshachi and Safapour, 2019; Gajić and Palčič, 2019; Jarkas, 2017; Geraldi and Adlbrecht, 2008; Nguyen et al., 2015; He et al., 2015; Bosch-Rekveldt et al., 2011; Chapman, 2016)
		Number of engineering hours	(Bosch-Rekveldt et al., 2011)}(Mirza and Ehsan, 2017)
		Budget	(Dao et al., 2017; Mirza and Ehsan, 2017; Nguyen et al., 2015; Xia and Chan, 2012; Bosch-Rekveldt et al., 2011; Chapman, 2016) Gajić and Palčič (2019)
Task	Piece of work\activity undertaken during the project duration	Numerous tasks	(He et al., 2015; Baccarini, 1996; Gajić and Palčič, 2019; Nguyen et al., 2015; Bosch-Rekveldt et al., 2011)
		High variety of task	(Mirza and Ehsan, 2017; Baccarini, 1996; Gajić and Palčič, 2019; He et al., 2015)
		Difficulty of task	(Baccarini, 1996; Chapman, 2016; He et al., 2015)
		Project scheduling	(Nguyen et al., 2015; Xia and Chan, 2012; Dao et al., 2017; Ahn et al., 2017)
		Rigidity of sequence	(Jarkas, 2017)

		Quality requirement	(Dao et al., 2017; Kermanshachi et al., 2018; Mirza and Ehsan, 2017; Kermanshachi and Safapour, 2019; Xia and Chan, 2012; Gajić and Palčič, 2019)
		Construction methods	(Xia and Chan, 2012)
		Lack of technical methods	(He et al., 2015; Chapman, 2016; Kermanshachi et al., 2018)
		Availability of skilled workforce	(Dao et al., 2017; Kermanshachi et al., 2018; Kermanshachi and Safapour, 2019; Gajić and Palčič, 2019; Jarkas, 2017; Bosch-Rekveldt et al., 2011; He et al., 2015)
Design complexity	Difficulty understanding and translating project drawings	Level of detailing	(He et al., 2015; Kermanshachi et al., 2018; Kermanshachi and Safapour, 2019; Jarkas, 2017; Xia and Chan, 2012)
		Structural elements	(Gajić and Palčič, 2019)
		Clarity of functions	(Gajić and Palčič, 2019)
		Variety of drawings	(Kermanshachi et al., 2018; Kermanshachi and Safapour, 2019; Jarkas, 2017)
		Project scope	(Dao et al., 2017; Bosch-Rekveldt et al., 2011)
		Physical location	Kermanshachi et al. (2018); (Dao et al., 2017; Mirza and Ehsan, 2017; Baccarini, 1996; Kermanshachi and Safapour, 2019; Jarkas, 2017; Chapman, 2016)
		Multiple locations	(Kermanshachi et al., 2018; Mirza and Ehsan, 2017; Kermanshachi and Safapour, 2019; Gajić and Palčič, 2019)
		Site topography	(Xia and Chan, 2012; Jarkas, 2017)
		Dynamic Complexity Dimension	
Project Features	Distinctive project attributes	Project duration	(Mirza and Ehsan, 2017)}(Bosch-Rekveldt et al., 2011; Chapman, 2016; Gajić and Palčič, 2019)
		Project tempo	(Xia and Chan, 2012; Dao et al., 2017; Bosch-Rekveldt et al., 2011)
		Construction methods	(Xia and Chan, 2012; Chapman, 2016)
		Uncertainty in methods	(Dao et al., 2017; Mirza and Ehsan, 2017; Gajić and Palčič, 2019; Bosch-Rekveldt et al., 2011; Lebcir and Choudrie, 2011; He et al., 2015)
		Reliance on other projects	(He et al., 2015)
		Project team's capability	(Dao et al., 2017; Kermanshachi et al., 2018)
		Geological conditions	(Xia and Chan, 2012; Chapman, 2016; Nguyen et al., 2015)

		Immediate environment	(Xia and Chan, 2012; Dao et al., 2017; Gajić and Palčič, 2019)
		Multiple time zone	(Dao et al., 2017; Mirza and Ehsan, 2017)
		Disperse team	(Mirza and Ehsan, 2017; Kermanshachi and Safapour, 2019; Gajić and Palčič, 2019; Kermanshachi et al., 2018)
		Deployment of plants	(Jarkas, 2017)
		Form of contract	(Dao et al., 2017; Bosch-Rekveldt et al., 2011; Geraldi and Adlbrecht, 2008; Nguyen et al., 2015; Xia and Chan, 2012)
Project Goals	Project desired results	High number of goals	(Gajić and Palčič, 2019)
		Lack of clear project goal	(Gajić and Palčič, 2019; Bosch-Rekveldt et al., 2011; Baccarini, 1996; He et al., 2015; Geraldi and Adlbrecht, 2008)
		Multiple project goals (multidisciplinary members)	(Gajić and Palčič, 2019)}(Baccarini, 1996; Bosch-Rekveldt et al., 2011)
		Variety of perspective	(Dao et al., 2017; Mirza and Ehsan, 2017; Nguyen et al., 2015; Bosch-Rekveldt et al., 2011; Gajić and Palčič, 2019)
Project Scope	Amount of work required to complete a project	Scope ambiguity	(Kermanshachi and Safapour, 2019; Dao et al., 2017; Baccarini, 1996; Jarkas, 2017; Bosch-Rekveldt et al., 2011; Nguyen et al., 2015; Xia and Chan, 2012; Gajić and Palčič, 2019)
		Scope uncertainty	(Kermanshachi and Safapour, 2019; Dao et al., 2017; Mirza and Ehsan, 2017; Jarkas, 2017; Bosch-Rekveldt et al., 2011; Ahn et al., 2017)
		Project detail and drawing.	(Jarkas, 2017)
		Change in project scope	(Dao et al., 2017; Kermanshachi et al., 2018; Mirza and Ehsan, 2017; Xia and Chan, 2012; Gajić and Palčič, 2019)
		Change in the project specification	(Kermanshachi et al., 2018)
		Inability to estimate accurately (timeline and budget)	(Dao et al., 2017; Mirza and Ehsan, 2017)
		Quantity of information to analyse	(Jarkas, 2017; Geraldi and Adlbrecht, 2008; Chapman, 2016)
		Quantity of information source	(Jarkas, 2017; Geraldi and Adlbrecht, 2008; Chapman, 2016)

2.3 The Project Manager

Successfully delivering highly complex mega-construction projects depends on the meticulous coordination and management of multifaceted technical components, diverse specialist teams, intricate schedules, and significant budgets by a highly competent project manager (Udo and Koppensteiner, 2004; Ding, 2016). While technical consultants may conceive of an ingenious project design, failure to seamlessly integrate and synchronise complex interdependent elements across fragmented teams, compressed timelines, and ambitious budgets can still lead to massive cost and schedule overruns or technical shortcomings without oversight from an experienced project leader (Ding, 2016).

As complex projects fundamentally depend on the oversight of experienced project managers for their success, these professionals perform an indispensable integrative role that requires advanced competencies (Söderlund et al., 2017). Extensive scholarship recognises project managers as essential "change agents" responsible for aligning diverse components to fulfil project objectives and goals through their expertise (Project Management Institute, 2019). However, merely embracing this change in agent designation will fail to ensure genuine effectiveness. Instead, project managers must cultivate specialised knowledge, abilities, behaviours, and contextual intelligence spanning multiple dimensions to master their complex roles (Crawford et al., 2005).

Extensive empirical research demonstrates that a project manager's specialised competencies in communication, stakeholder engagement, technical knowledge, leadership, organisation, and strategic decision-making directly enable robust coordination, astute risk mitigation, motivational team leadership, and proactive issue resolution required for optimal megaproject delivery (Crawford et al., 2006; Dias et al., 2014). Given these well-established findings, leading construction firms invest substantially in recruiting and developing highly credentialed project managers, thereby achieving superior performance.

However, merely designating managers based on reputation fails to guarantee the genuine competence needed for megaproject complexity, often resulting in substantial resource wastage and less-than-optimal outcomes (Müller and Turner, 2007a). Moreover, traditional project management strategies frequently prove inadequate for systematically cultivating the full range of sophisticated cognitive, technical, leadership, and contextual competencies needed to dynamically manage multifaceted megaproject complexities under intense constraints (Remington and Pollacks, 2016).

This underscores the need for research to elucidate the specialised competencies most critical for mega construction projects as a basis for evaluating strategies to enhance project management capabilities. As complexity management is recognised as imperative yet underexplored in megaprojects (Bosch-Rekveldt et al., 2011; Maylor and Turner, 2017), a targeted investigation of vital competencies and strategic augmentation approaches is warranted. The next section critically examines the prevalent project manager competence factors essential for managing complexity in mega construction projects to establish a foundation for this research.

2.4 Project Management Competence

Despite growing recognition of its pivotal role in project success, the conceptual definition of competence in construction project management remains inadequately delineated in extant literature (Ding, 2016). Notable studies by Omar and Fayek (2016) have demonstrated complex construction project management by competent project managers. However, inconsistencies and limitations persist regarding the precise terminology and boundaries that differentiate competence, competency, and competence. As Palan (2003) notes, competence broadly encompasses an individual's qualifications, abilities, and fitness to undertake highly complex leadership roles to optimise project performance. However, there are discrepancies in categorising specific elements of competence versus competency.

For instance, Ahadzie et al. (2008) differentiated competence as a measurable performance attribute related to planning, organising, coordinating, and controlling projects, whereas competency refers to contextual attributes and personality traits that enable organisational effectiveness. Alternatively, Dias et al. (2014) defined competency as a personal attribute that influences capabilities (worker-oriented) and competence as demonstrable achievements in specific job performance (work-oriented). Through a systematic competency framework review, Ding (2016) describes "project management competence as the proven ability to apply a particular combination of knowledge, skills, and personal characteristics to accomplish observable outcomes for a given task within a project setting."

Notwithstanding these attempts at definition, inconsistent terminology has created confusion when delineating the specific skills, behaviours, and qualities needed to handle complex situations. This study emphasises competence as encompassing both competence and competency constructs, referring to the demonstrated capabilities of a project manager that enable the effective management of complexity in large-scale construction projects, recognising the critical role of project managers' competence in navigating complexity during the construction process.

Moreover, knowledge gaps persist regarding how project managers can systematically enhance their competence to achieve optimal outcomes amid multifaceted complexities in practice (Nyarirangwe and Babatunde, 2021). Therefore, this study examines whether implementing digital construction methods and technologies can effectively augment project managers' competence in managing the complexity of mega-construction initiatives in Nigeria. Elucidating this relationship requires first establishing conceptual clarity on contextualised competence factors as the underlying foundation, as highlighted in the behavioural dimension of complexity management in Section 1.2.

2.4.1 Competence Framework

With increasing project complexity in the 21st century, strategies to enhance managerial competence capable of mitigating complexity implications have garnered increasing attention (Maylor and Turner, 2017). Prominent competence frameworks advocate project managers' self-assessments to foster preparedness in complex environments. For instance, the Project Management Institute (2002) developed a competency framework comprising knowledge, performance, and personal pillars to strengthen competence and provide guidelines for advancing practices amid complexity.

Similarly, the International Project Management Association [IPMA] (2009) formulated the competence baseline 3.0 framework, encapsulating technical, behavioural, and contextual dimensions. Concurrently, the Association for Project Management (2008) created a competence categorisation, delineating manager competence levels across the four proposed dimensions to ensure compatibility between managers and project types based on competence. In contrast, the International Centre for Complex Project Management (2012) states that only peer-certified individuals with superior competence can handle highly complex projects. To further refine competence understanding, IPMA (2015) introduced the individual competence baseline 4.0, distinguishing people, practice, and perspective competence dimensions. People's competence comprises personal and interpersonal leadership traits; practice covers defined methods, tools, and techniques; perspective involves processes, tools, and techniques for environmental interaction (International Project Management Association [IPMA], 2015).

Despite advances in competence development, the pace of improvement lagged amid the rapid evolution of complexity. Consequently, researchers have proposed incorporating a novel competence dimension, premising that identifying critical competence factors per project type would enhance performance (Chen et al., 2008). Spencer and Spencer (2008) proposed five competence characteristics—motivation, traits, self-concept, knowledge, and skills. They highlighted motivation, traits, and self-concept as inherent and challenging, whereas other characteristics developed through extensive training. Shah and Prakash (2018) developed a universal competency model to improve infrastructure project performance across strategic, analytical, personal, managerial, professional, and leadership dimensions. The professional dimensions of problem-solving, assertiveness, creativity, and proactiveness are particularly relevant to this study.

While frameworks have evaluated managerial competencies, competing and diverging views on competence dimensions exist because of the distinct study contexts. Competence has been examined from both the industrial (Dainty et al., 2004; Ding, 2016) and project-type perspectives (Ahadzie et al., 2009; Abdullah et al., 2018). Technical and behavioural dimensions are prominent in the construction management literature. This study focuses on technical competence for two reasons: the construction phase is predominantly technical, and prior research shows a correlation between technical competence and complexity management (Dias et al., 2014). Consequently, the technical dimension is the focal point of this research, elaborated in the next section and presented in Chapter Five.

2.4.2 Technical Competence Factors

Technical competence encapsulates the requisite skills, traits, and knowledge of key processes, methods, materials, equipment, planning, scheduling, cost management, and safety measures, which are crucial for superior performance in highly complex and technological projects (Lampel, 2001). Recognising its significance has led to emerging research elucidating essential technical competence factors across industrial and project contexts (Ahadzie et al., 2008). Through quantitative construction project management literature, Dias et al. (2014) identified leadership, openness, reliability, engagement, and ethics as competencies that influence all project types, with variable impacts based on the application area, complexity, and innovation levels. By evaluating International Project Management Association guidelines, they established a correlation between technical competence and complexity management. Further, they suggested that the focused development of the identified factors could empower construction firms to enhance performance, although specific recommendations for competence enhancement were lacking.

In a distinct research, Ahadzie et al. (2009) used a structured questionnaire to determine the expected technical competencies of housing construction project managers in developing countries. The findings highlight site layout planning, construction technology proficiency, conflict resolution, accessibility, punctuality, dedication, and selflessness towards teams. Abdullah et al. (2018) examined the required technical competencies, identifying project resource management, site administration, preconstruction coordination, technological agility, and contractual enforcement as the most significant for optimal performance.

Chen et al. (2008) revealed that the conception determinants of competence are planning ability, construction work knowledge, and commercial management. Through an industry survey, Edum-Fotwe and McCaffer (2000) identified leading, communicating, negotiating, and problem-solving as foundational knowledge and skills construction managers perceived as essential for competence development, primarily acquired through experience. In capturing active managers' experiences, Lei and Skitmore (2004) highlighted communication, meeting objectives, and decision-making as vital for industry survival. Later research by Li et al. (2020) identified fundamental knowledge, goal orientation, uncertainty management, and stakeholder engagement as key international project manager competencies. Bashir et al. (2021) highlighted coordination, resource planning, negotiation, and scope definition as critical competencies for international development projects.

Moradi et al. (2020) identified group capabilities, stress tolerance, order maintenance, and relationship building among ten essential competencies for collaborative construction projects, which are critical for mega infrastructure projects thriving on collaboration. Dainty et al. (2004) proposed a competency-based model for managers to identify critical competencies to ensure superior infrastructure project performance. In alignment with this, Crawford (2005) described competence as more than a success factor, rather, it is part of the standards guiding project team development and assessment. Table 2.3 summarises the relied-upon infrastructure construction competence factors. However, due to limited research resources, Study β focused on capturing the most salient technical factors relevant to the Nigerian context, emphasising those profoundly impacting construction.

Table 2.3 Project Manager's Competence Factors

Competence	Description	Reference
Leadership	Possess the ability to evaluate technical concepts needed to make the right decisions to keep a project on track and effectively involve all stakeholders.	Kerzner (2017), Dias et al. (2014), Edum-Fotwe and McCaffer (2000), Nguyen et al. (2004), (Müller and Turner, 2010), , Chen et al. (2008), Ahmed et al. (2013), Ahadzie et al. (2009)
Planning	An awareness of the definite project scope and design schedule ensures the project performs its expected goals.	Zhao et al. (2010); Kerzner (2017), Turner (2009), Cooke-Davies (2002), Gudienė et al. (2014), (Ding, 2016), Chen et al. (2008)¸ Dainty et al. (2004)
Communication	Ability to provide clear and concise information to clarify work direction and pass in a timely fashion amongst project participants.	Ding (2016), Dias et al. (2014), Dainty et al. (2004), Edum-Fotwe and McCaffer (2000), (Lei and Skitmore, 2004)
Effective decision-making	Possess the ability to identify the best choice among alternatives in the face of uncertainty.	Larson and Gray (2017), Pinto and Winch (2016), Winch (2010), Turner (2009), (Lei and Skitmore, 2004)
Supervision and monitoring	Ensure strict compliance at work and keep track of project team performance to ensure they are working towards the project goal.	Silva et al. (2017), Fisher (2011), (Gudienė et al., 2014), Ding (2016), Dias et al. (2014), (Lei and Skitmore, 2004)
Coordination	Meeting and working with line management, external contractors, sub-contractors, and management.	Müller and Turner (2010), Kerzner (2017), Yamin and Sim (2016), Dias et al. (2014), Ding (2016)
Directing	Being able to dictate the most prudent way to implement tasks and manage project resources efficiently.	Gudienė et al. (2014), Ding (2016), (Kerzner, 2018), Dias et al. (2014), Ding (2016), Ahmed et al. (2013)
Motivates team	Can motivate the project team through normal work pressure and political realities and pressures.	Fisher (2011), Young and Dulewicz (2009), Nguyen et al. (2004), Ding (2016), (Dias et al., 2014), Chen et al. (2008)
Conflict resolution	He or she understands that conflicts are inevitable; when such occurs, he or she could analyse the cause and respond appropriately to resolve them.	Fisher (2011), Kerzner (2018), Müller et al. (2007), Müller and Turner (2010), Ahadzie et al. (2009)
Administering	Project managers are expected to perform various administrative tasks without support.	Ding (2016), Dias et al. (2014), Ahmed et al. (2013), Ahadzie et al. (2009), Dainty et al. (2004)

Negotiation	Possess the demeanour to persuade project stakeholders and participants by providing a convincing rationale to obtain their support to foster project performance.	Kerzner (2018), Turner (2009); (Ochieng et al., 2013), Ahmed et al. (2013), Edum-Fotwe and McCaffer (2000)
Aptitude	Able to adapt to scope change and be flexible to fit into new cultural realities in the project environment.	Ding (2016), Dias et al. (2014), Dainty et al. (2004)
Confidence and commitment	Possesses a firm belief in himself and is fully committed to the project's goals and objectives.	Ding (2016), Dias et al. (2014), Larson and Gray (2017), Ahmed et al. (2013), Ahadzie et al. (2009)
Problem-solving	Keeps an eye on project outcomes rather than waiting for a situation to occur before reacting.	Ding (2016), Dias et al. (2014), Kerzner (2017), (Zavadskas et al., 2014) Edum-Fotwe and McCaffer (2000)
Open-mindedness	Open to innovative ideas without prejudice.	(Pinto and Winch, 2016) , Ding (2016), Dias et al. (2014),

2.5 Project Management Strategy

Project management emerged in the 1950s to deliver projects efficiently, driving the development of methods, techniques, and processes combined into strategies or methodologies. These principles and guidelines were developed to enhance efficiency (van der Hoorn, 2016). Project management strategies comprise related practices, methods, techniques, tools, and processes that define an approach for planning, developing, controlling, and delivering projects throughout their lifecycles (Besner and Hobbs, 2013). De-Carvalho et al. (2015) describe strategy as the sequential application of processes to institutionalise best practices.

As megaprojects become more complex, strategies have evolved to align with contemporary characteristics (Ghaleb et al., 2022). However, despite the evolution of mega-infrastructure projects, performance still needs improvement, with approximately 90% underperforming annually (Flyvbjerg, 2017). Traditional strategies may need to be revised for contemporary projects owing to their inherent changes. Nonetheless, suitable strategies that enable effective complex navigation and infrastructure delivery have been pursued (Nyarirangwe and Babatunde, 2021).

Although numerous strategies exist, complex challenges remain unresolved with minimal changes (Bilgin et al., 2022). Davies and Mackenzie (2014) contended that no single strategy can predict every complex project. Contradicting this premise, Sage et al. (2014) emphasise selecting appropriate strategies based on context, size, budget, and requirements. For megaprojects, suitable strategies are critical success factors that enhance effectiveness and success probability (Maylor and Turner, 2017).

Infrastructure project managers face strategy-selection challenges due to inherent project differences (Shenhar and Dvir, 2008). To address this issue, Shenhar and Dvir (2008) developed a framework that aligns individual project types with the most appropriate management strategy based on pace, technology, complexity, and novelty. The study recommends that organisations develop project management strategies tailored to each project type. Contingency theory posits contextual selection as circumstances that necessitate different strategies for success (Howell et al., 2010). Crucially, this highlights the limitations of construction industry tools correlating strategies to project types, thus perpetuating underperformance (Kermanshachi et al., 2021).

Traditional strategies utilise work breakdowns, critical paths, requests for information, and drawings to facilitate coordination, monitoring, decision-making, and resource allocation (Kerzner, 2017). However, these strategies are considered inadequate and counterproductive for complex projects and are unable to handle evolving requirements and scope changes (International Centre for Complex Project Management, 2012). This limitation, compounded by substantial paperwork requirements, results in managers spending an inordinate amount of time on documentation rather than on effective project execution (Fewings and Henjewele, 2019).

In response, the industry shifted post-‘Rethinking Construction, integrating manufacturing and information technology strategies, such as Lean, Six Sigma, Agile, and Concurrent Engineering, to foster best practices (Egan, 1998). Lean initially emphasised maximum value specification, eliminating waste, and improving quality (Koskela et al., 2002). Planning and controlling uncertainty through organisations and visuals situates managers as the last project planners (Aziz and Hafez, 2013). Agile is flexible and dynamic, responding to change and promoting software over documentation. Work processes are decomposed into manageable components with team collaboration to design workflows instead of rigid predetermined processes (Saini et al., 2018).

Furthermore, Six Sigma relies on statistical process control, failure mode analysis, and control charts to improve processes. The Define, Measure, Analyse, Improve, Control (DMAIC) paradigm stipulates that controlling inputs ensures desired outputs through quantified risk-taking and data-driven decisions (Siddiqui et al., 2016). Concurrent Engineering emphasises parallelism, integrating design and production to reduce lead-times, improve quality, and decrease costs (Mansoor and Khalfan, 2001). This is optimal for well-defined scoped projects. Additionally, programme management is vital, particularly for mega-projects, managing interrelated projects as a coordinated program rather than individually (Shehu and Akintoye, 2010). It enables integrated planning, coordination, scheduling, and cost control and improves performance (Shehu and Akintoye, 2009a). It also allows direct contractor liaison while the program manager operates from the headquarters.

In light of the various suggested methods, the outcomes of their implementation were disappointing, as they were rooted in the foundational assumption that comprehensive initial planning leads to flawless execution. However, this inadequately addresses unforeseen realities, particularly for mega-infrastructure (Nyarirangwe and Babatunde, 2021). Unforeseeable events often exceed traditional strategy capacity. Formulated predominantly for planning, when complexity arises on-site, these strategies may need to be revised for managers to respond appropriately (Howell et al., 2010).

Recognising these limitations, responsive, forward-looking strategies are required to manage infrastructure complexities (Kermanshachi et al., 2021). Strategies must enable prompt information translation into actionable measures to recalibrate trajectories as needed. Digital Construction, as explored by Woodhead et al. (2018) and the Construction Industry Training Board [CITB] (2018), is promising. This is an emerging strategy analogous to digital manufacturing. This research ascertains whether adopting Digital Construction can enhance project managers' competence in navigating large-scale infrastructure complexity. Focusing on megaprojects is relevant because they are typically undertaken by well-resourced multinational firms that are capable of leveraging industry digital tools (Blanco et al., 2017). Digital Construction may revolutionise complex construction management and execution, as posited in the current study. The next section explores digital construction and its relevance to mega-constructions

2.6 Digital Construction Strategy in Construction

In the 21st century, digital technology has become integral to business operations by improving efficiency, reducing costs, and fostering innovation and forward-thinking (Jones, 2017). The pre-digital era relied on heavy machinery for efficiency and software support (Skripak, 2016).

However, contemporary firms leverage advanced digital tools for a competitive advantage, bringing about revolutionary production processes and methodological changes. This transformation realigned the industry dynamics more substantially than prior technological revolutions (Barbosa et al., 2017). For example, in entertainment, streaming displaced record labels and movie studios, while in transportation, autonomous vehicles and ride-hailing disrupted the industry by simplifying access through technology (Jones, 2017).

Although unrelated to construction, digital transformation has gained traction in manufacturing, a sector where construction has previously benchmarked other strategies. Manufacturers have adopted innovative production strategies to consolidate their core competencies into integrated networks (Brettel et al., 2014). This has spurred the adoption of digital strategies and integrated tools to manage complexity and improve performance. In manufacturing, digital strategies leverage collaborative platforms to integrate supply chains and enable inter-company operations with real-time product and process data (Theorin et al., 2017). It also facilitates human-machine communication for the digital engineering of products and processes. Furthermore, they enable the simulation and modelling of flexible products and real-time production changes (Brettel et al., 2014). Accordingly, digital strategies enhanced managerial dynamic capabilities to manage complexity and encapsulate Industry 4.0 essence.

Despite these advancements, construction, a pivotal sector that provides tangible assets, has stagnated over the past century (Green, 2016). Although potentially beneficial, digital transformation in construction remains slow. Construction is among the least digitalised sectors, ahead of agriculture (Barbosa et al., 2017). Stakeholders apprehension, limited legislative enforcement, prohibitive digitisation costs, insufficient expertise, and inadequate client buy-in have contributed to slow digital adoption (Sacks et al., 2016).

Digital tools have exhibited immense potential for improving construction delivery and environmental development. Applying such tools in construction comprises a digital strategy combining tools to ensure safe, efficient, and collaborative operations, targeting better outcomes at all project lifecycle stages (Catlin et al., 2018). The term ***"digital construction"*** was coined by stakeholders as an initiative to boost productivity (Woodhead et al., 2018). Digital tools range from communication and collaboration platforms that obviate travel needs to design, monitor, and store information software to improve production processes and modern material use. According to

Kapogiannis (2018), optimal implementation integrates people, processes, and technology into a comprehensive strategy, reminiscent of digital manufacturing strategies.

Digital tool use has recently surged to address industry challenges, enabled by a collaborative paradigm shift involving mandated Building Information Modelling (BIM) adoption (Walker and Lloyd-Walker, 2016). BIM harmonises and facilitates multitool use (Catlin et al., 2018). This strategy has improved productivity, complexity management, predictability, client satisfaction, and lifecycle information archiving. Collaborative software and BIM models help managers identify and mitigate inefficiencies early (Vogl and Abdel-Wahab, 2014).

While BIM enables most construction digital tools, leading to misconceptions of BIM nD representing total digital construction (Svalestuen et al., 2017), CITB (2018) emphasised digitalisation as much broader than BIM. Digital construction encompasses processes, technology, and people central to achieving the business and construction objectives. Adoption in countries such as the USA, Australia, and Western Europe has yielded competitive advantages across the project lifecycles (Paterson et al., 2015). Productivity has increased substantially, and investment returns have been achieved through shorter cycles, paperwork, and material loss savings (Agarwal et al., 2016). Examples include energy savings from hotel renovations in the USA and cost and time savings for highway projects using fleet management and routing software (Gerbert et al., 2016).

Holistic civil works digitalisation could generate major global engineering, construction, and operational cost savings in the coming decades (Gerbert et al., 2016). Most studies have shown that digital construction augments competence across different dimensions. Blanco et al. (2017) emphasised its indispensability for mega infrastructure, enhancing safety, efficiency, budget adherence, and complexity management. This study examines how adoption boosts project managers' competence to manage mega-infrastructure complexity and improve their success. It presents literature showcasing tool combinations (Table 2.4) supporting competence in managing construction complexity, as discussed in the next section.

Table 2.4 Digital Tools for Infrastructure Construction

Construction Technology	Support proffered to Construction	Reference
BIM	Decrease in RFIs and RFCs Better construction documents Reduction in material waste Reduction in scheduling cost Reduction in final construction cost Reduction in reportable safety incidents Improves information mobility Improves collaboration on the project Reduction in unanticipated problems Reduces the need for rework Fewer paper documents Improved productivity	(Chen and Tang, 2019; Chen and Lu, 2019; Irizarry et al., 2013; Dossick and Neff, 2011; Matthews et al., 2015; Sacks et al., 2016)
Augmented and Virtual Reality	Enhance customer acceptance Identify potential problems early on Customer satisfaction Participatory Design Real-time Feedback Safety Improvement Simulation Training Accelerates Decision Making Reduces need for rework	(Wang et al., 2014; Kim et al., 2013; Zhou et al., 2017)
3D Printing	Increases Speed Reduces Cost for both Material and Labour Higher Precision During the Construction Process Enhances Safety Sustainability Risk Mitigation Complexity and Design Freedom Simplifies on-site logistics Customization Weather Concerns Mitigation Less disruption to the surrounding environment Reduces the need for rework	(Tay et al., 2017; Buswell et al., 2018)
Modern Construction Methods (Prefabrication, Modularization and Precast Construction)	Speed of construction Enhanced quality Decreased material waste Simplified on-site logistics Economic Improvement Less disruption to the surrounding environment Weather Mitigation	(Zhong et al., 2017; Wang et al., 2020)

Robotics	Reduced need for rework Increased Safety Higher Precision During the Construction Process Increased Speed Reduced need for rework Dangerous task done with ease Simplified on-site logistics Workforce Augmentation Improved productivity Economic Improvement	(Yang et al., 2019)
Blockchain	Transparency about data ownership Project modelling Smart contracts Construction delays due to overdue payments Accountability Reduce Litigation Inspection and delivery	(Wang et al., 2020)
Drones	Tracking job progress Logistics and production planning Enables inspection in areas impossible to access. Safety monitoring and support Land surveying, thermal imaging, laser scanning, and other data collection	(Jiang et al., 2015; Cleden,2017)
Radio Frequency Identification Technology (RFID)	Logistics and supply chain visibility Inventory tracking Personnel tracking and timekeeping Materials management • Access control Asset and equipment tracking Tool tracking Facility Management Real-time location systems ("RTLS")	(Lu et al., 2007; Woo et al., 2011; Liu et al., 2013)
The Internet of Things and Advanced Analytics	Equipment monitoring and repair Inventory management and ordering Quality assessment Energy efficiency – Safety improvement Predictive design Speed of construction Planning Facility Management Improve onsite equipment maintenance	(Zhong et al., 2017; Sacks et al., 2020a; Sacks et al., 2020b)
Wearable technology	Improve Employee satisfaction and productivity Better Jobsite Visibility Better Reporting	(Kritzler et al., 2015)

	Improved workflows Improves safety Recorded performance appraisal	
Higher definition surveying and geolocation	Electronic distance measurement Improved GPR and magnetometers More accurate Global Positioning System (GPS) Project Planning and Inspection Site Reconnaissance Performance Tracking	(Lu et al., 2007; Liu et al., 2013; Jiang et al., 2015; Puri and Turkan, 2020)

2.6.1 Application of Digital Construction Strategy on Mega Infrastructure Projects.

Communication

Mega infrastructure development requires collaboration among various professionals to yield the final product. Ineffective communication between project managers and diverse participants is a significant hurdle during construction, with information dissemination deficiencies being identified as the primary cause of suboptimal performance (Senescu et al., 2013). Research indicates that more than just using communication tools is required for streamlining protocols. Instead, a comprehensive strategy combining digital tools could ensure timely information collection and dissemination between managers and participants. Supporting this notion, Wang et al. (2014) demonstrated that integrating BIM information models with augmented reality stimulates human sensations through both real and virtual information sources. This digital strategy simplifies problem-solving, minimises rework, and enables managers to communicate design specifications more lucidly among teams.

Zhong et al. (2017) proposed the Internet of Things (IoT) to provide real-time visibility and traceability in prefabricated construction by integrating BIM 3D models with RFID technology. The system augments managerial communication and information management competence by enabling ready work-schedule updates and real-time multiparticipant information sharing. Similarly, Kim et al. (2013) showed that smartphones could enhance onsite management by integrating wireless communication and augmented reality into a client-server database. Using mobile computing technology, managers effectively monitor progress through augmented visualisation, concurrently scheduled tasks, and communicated plans in real time among teams. This notably reduced construction time by enabling remote progress monitoring, document access, and design change communication without repeated travel between the site and the office.

In summary, the synergistic integration of complementary digital tools can effectively augment project manager communication competence, enabling proper infrastructure complexity management through real-time communication, monitoring, and problem solving in the multifaceted context of mega-infrastructure development.

Planning and Coordination

Mega-infrastructure construction requires the input of numerous professionals and extensive resources. Thus, project managers must schedule activities and allocate resources (e.g. budgets, materials, and personnel) in a coordinated approach to effectively achieve their intended objectives (Andy and Price, 2010). The inherent complexity of the construction process, characterised by a high number and variety of tasks, task difficulty, and number of involved workers, necessitates effective coordination by the project manager to optimise performance and productivity (Ochieng and Hughes, 2013). Indeed, the effectiveness of the chosen coordination method is integral to optimising the construction planning and coordination. As noted by Chang and Shen (2014), the effectiveness of the selected coordination method plays a crucial role in optimising construction planning and coordination. Consequently, considerable research has been conducted to identify effective coordination methods that aid project managers in navigating complexity and managing information exchanges in large-scale construction projects (Senescu et al., 2013).

Recent studies have proposed that project managers can coordinate infrastructure construction proactively by incorporating digital construction. Wang et al. (2013) proposed a framework that integrates BIM 3D information models and augmented reality to allow project managers to monitor and coordinate on-site construction activities. This study further proposed integrating tracking and sensing technologies, such as RFID, laser pointing sensors, and monitor tracking, to enhance resource distribution planning and coordination at construction sites. Lu et al. (2007) elucidated how the combination of a Global Positioning System (GPS) and Radio Frequency Identification (RFID) could enable project managers to track equipment on mega-infrastructure sites. This is particularly significant given that locating equipment, scheduling its usage, and delegating tasks are notable sources of complexity in large-scale engineering projects (Nasir et al., 2010).

Woo et al. (2011) demonstrated how fingerprints from Received Signal Strength Indication (RSSI), communicating with various RFID tags, were combined to develop a Wi-Fi-based indoor system. This system allowed for effective monitoring of labour, materials, and vehicle location during shield tunnel construction, enhancing the project manager's planning competence to conduct labour productivity analysis and allocate resources accurately.

Kim and Chi (2020) put forth a multi-camera vision-based productivity monitoring methodology that assists project managers in coordinating machinery on earthmoving projects. This method merges and matches image data from multiple camera sources onsite using single-camera vision-based equipment, enabling project managers to analyse equipment productivity and make optimal usage decisions to maximise onsite operational capacity. Jiang et al. (2015) integrated a Global Positioning System (GPS) and Geographic Information System (GIS) using smart mobile devices to develop a labour consumption measurement system. This system allows managers to monitor the number of workers and their on-site activities and track the productivity levels of specialist subcontractors. It also provides managers with pertinent project data, facilitating specialist contract negotiations, and claim reconciliation.

Irizarry et al. (2013) proposed a construction supply chain management framework that integrates 3D information modelling and geographic information systems (GIS) to form a proactive system. This system allows managers to visualise supply chain status and receive early warning signals regarding material delays, thereby ensuring timely material delivery during construction. Finally, Sacks et al. (2020a) advanced the digital twin construction (DTC) technique as a proactive approach to managing, coordinating, and planning building information throughout its lifecycle. This technique builds on the prevailing concepts of Building Information Modelling (BIM), lean project production systems, automated data acquisition from construction sites, and supply chains.

In conclusion, adopting digital construction techniques and integrating advanced technologies on-site can significantly augment project managers' planning and coordination competencies, enabling effective information exchange, task monitoring, and resource optimisation amid the multifaceted complexities of mega-infrastructure projects.

Decision-making

Mega infrastructure projects are inherently dynamic and frequently undergo changes during construction that require timely and assertive managerial decision-making to align outcomes with objectives and effectively manage complexity (Salet et al., 2013). Various models have been developed to aid in construction decision-making. However, some studies suggest that managers' decisions stem from their inherent competence (Dainty et al., 2004) or experience (Moradi et al., 2020).

While relying on competence or experience seems practical, this approach can be ineffective given each project's unique challenges, particularly in mega-infrastructure, where unfamiliar scenarios inevitably arise. As argued, research convincingly shows that project managers can make comprehensive outcome-influencing decisions on complex projects by adopting contingent strategies. Experts have recommended digital tools for streamlining decision-making (Love et al., 2015). However, a more responsive approach could integrate these tools into a comprehensive digital construction strategy to overcome individual tool limitations and enhance competence.

Although conceptually outlined, substantive empirical research in this area is limited. For example, Wang et al. (2019) proposed a utility management framework integrating BIM 3D models and GIS to assist project managers by disseminating information, improving individual utility components and spatial network management, and enhancing underground utility decision-making in urban settings. Similarly, Puri and Turkan (2020) proposed combining mobile LiDAR and 4D BIM data into a progress tracking framework to facilitate real-time monitoring, performance appraisal, and decision-making aligning with performance.

Zhou et al. (2017) suggested using augmented reality and BIM models for segment displacement inspection during tunnelling to address utility pipe construction damage. This enabled seamless on-site inspections by overlaying a virtual quality baseline from the BIM onto the actual segment displacement using augmented reality. Revealing discrepancies helped managers assess tunnel structural safety, analyse potential stabilisation methods, and decide the most appropriate approach to prevent accidents. Overall, while studies demonstrate the efficacy of digital construction for augmenting project manager competencies, construction firms need to implement integrated digital strategies on-site, which can enhance managerial decision-making processes amid the complexities inherent in mega-infrastructure projects.

Supervision and Monitoring

In construction project management, the terms "supervision" and "monitoring" are frequently used interchangeably, both referring to the oversight of tasks or activities. However, these processes are distinct. Supervision involves direct work processes and team observation while monitoring denotes passive work process observation, including evaluating project resources (materials, personnel, machines, and money) against the project baseline (Yu et al., 2007). Mega infrastructure construction complexities, such as expansive areas, numerous workers, and varied daily tasks, pose significant project management challenges for effectively executing supervisory and monitoring roles (Gidado, 1996).

Consider a manager who oversees over a hundred interrelated daily activities. The sheer volume and complexity can be overwhelming and counterproductive, respectively. McCullouch (1997) found that managers spend about 50% of their time collecting and analysing on-site data. Moreover, traditional monitoring has proved cumbersome, error-prone, and largely ineffective for managing mega-construction projects involving numerous concurrent activities. Often, the collected data becomes obsolete before corrective realignment is implemented. Studies have recommended structured training (Dias et al., 2014) to mitigate these issues and technological tools to enhance competencies (Panas et al., 2014). However, training has shown limited effectiveness because most programs assume predictable projects, often contradicting complex construction realities.

Given the limited training effectiveness and tool advantages, adopting digital construction strategies can enable project managers to handle complexity better. For example, Son and Kim (2010) proposed an automated 3D component recognition and modelling technique using a stereo vision system colour and 3D data. It assigns colours to building elements, enabling 3D analysis of the as-built models against the actual environment. Given the immense site size, this could facilitate construction output and productivity monitoring in the workplace. Matthews et al. (2015) examined using cloud-based BIM for real-time monitoring. However, its semi-automated processes and virtual environment limitations have made it cumbersome (Hilfert and König, 2016). Kang et al. (2016) combined 4D and 5D BIM simulation features with telepresence using a site webcam to develop a schedule management system. This provided real-time visual data on progress compared to the planned BIM CAD model, enabling proactive resource planning and baseline alignment.

Alternatively, Liu et al. (2013) developed an automatic control and monitoring system integrating RFID, GPS, GIS, personal digital assistants, and cellular networks to aid resource management and moisture monitoring for earth-rock dam construction. By combining tools, the system automated supervision determines the required water volumes to complement the compaction material types and volumes. Turkan et al. (2012) demonstrated merging 3D point clouds obtained from laser scanning with a 3D CAD model and schedule data (4D modelling) to develop automated construction progress tracking. This enabled accurate progress calculation and schedule updating by visually recording work progress through coordinate registration. Hence, adopting digital construction could significantly enhance monitoring, problem-solving, and performance in mega-infrastructure projects

2.7 Proposed Conceptual Framework

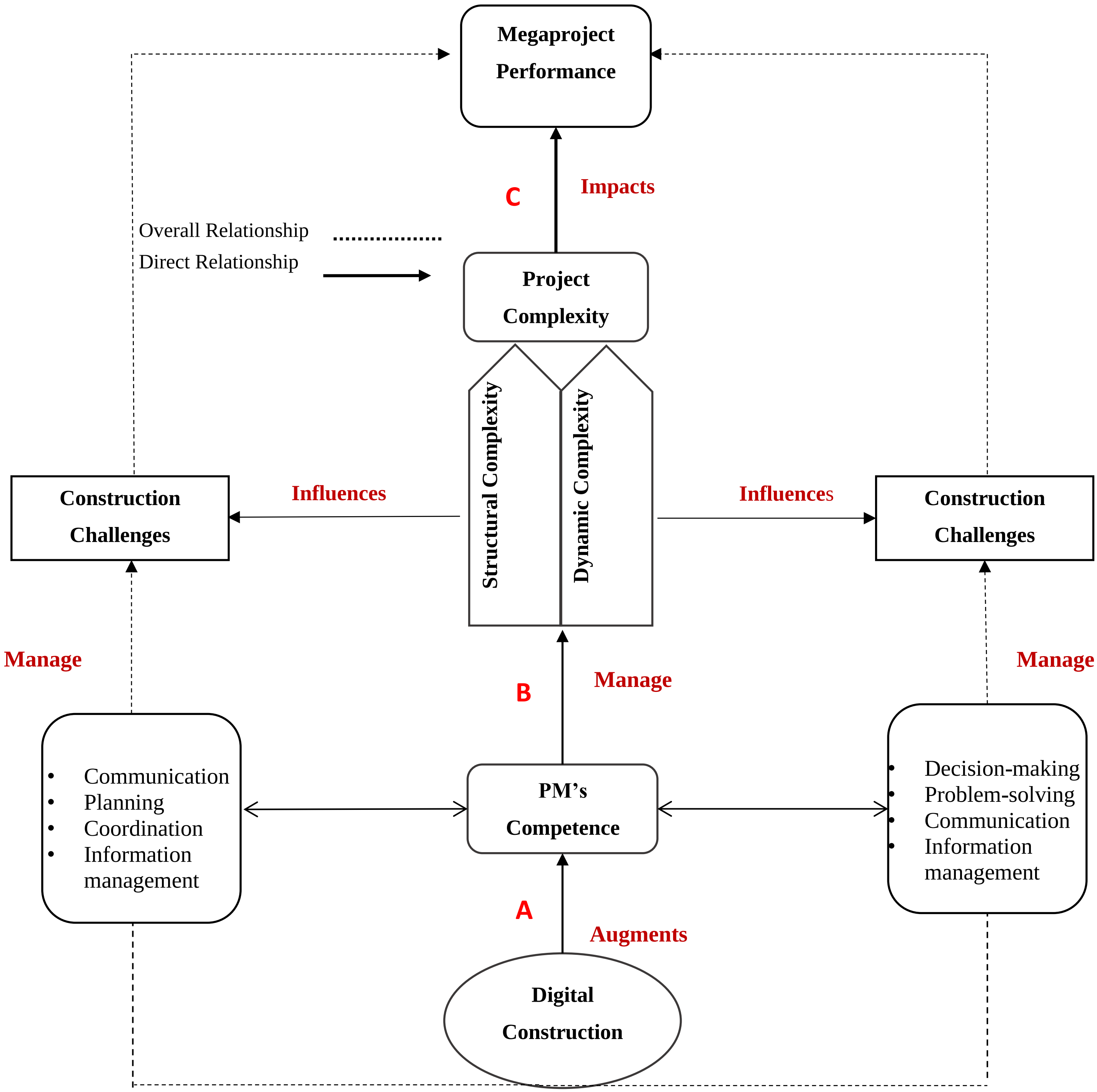

Figure 2.5 Proposed Conceptual Framework

This conceptual framework aims to improve the performance of mega-infrastructure projects in Nigeria through effective complexity management. Contingency management theory underpins this framework (Donaldson, 2001) and examines the complex interrelationships between key variables identified through an extensive literature review. Specifically, it focuses on the connections between project complexity, project manager competence, project strategies, and project performance outcomes (Relationships B and C). While prior research has attempted to enhance infrastructure project performance, persistent challenges remain in managing inherent complexities (Söderlund et al., 2017). The framework comprises four key components: project strategies, complexity factors, competence requirements, and performance indicators. It proposes that adopting digital construction technologies and methods can enhance project managers' competence in managing mega-construction complexities and improve project performance.

Drawing on contingency management theory (Donaldson, 2001), this framework recognises no singular optimal approach for managing construction projects. Instead, best practices and strategies are contingent on internal and external factors, including project complexity. Contingency theory suggests that project performance is optimised when internal project systems and processes align with the specific complexities involved (Howell et al., 2010). This perspective highlights the necessity of identifying key project complexity factors in each context as prerequisites for developing aligned management strategies. The framework aims to establish this contingency alignment by first examining the Nigerian construction environment to determine the primary complexity drivers (Study α). This informs the selection of appropriate strategies to enhance competence in managing the identified complexities (Deng and Smyth, 2013).

Contingency theory highlights that managerial competencies must be tailored and developed to match project characteristics (Teller and Kock, 2013). This aligns with the framework's proposition that digital construction can provide specific competency-building tools to assist project managers in addressing megaproject complexities in the Nigerian context. Specifically, this contingency perspective provides the rationale for the framework to identify the critical complexity factors in Nigerian mega-construction as a basis for selecting and aligning digital construction tools and strategies to enhance project management competence.

Having outlined the key components of the conceptual framework, the next section reviews the existing literature on the impact of project complexity on performance to validate Relationship C shown in the framework.

2.7.1 Competence in Managing Complexity (Relationship B)

Project manager competence is critical in conjunction with complexity (Relationship B). The International Centre for Complex Project Management (2012) proposed that only competent managers can effectively lead complex mega-projects. Further studies, such as that conducted by Mouchi et al. (2011), have reiterated the crucial role of optimal competence in managing complex construction projects, particularly mega-scale projects. Dias et al. (2014) established a strong correlation between technical competence and project complexity management, emphasising the critical role of competence in achieving project success. This study also found that a project manager’s level of competence significantly determines the probability of success in complex projects. This empirical evidence reinforces the contingent relationship between competence and the success of complexity management.

Further research on complexity provides insights into the specific competencies needed for effective management, particularly regarding structural and dynamic complexities. Brady and Davies (2014) proposed that managing structural complexity requires information management and coordination capabilities. Similarly, Geraldi and Adlbrecht (2008) emphasised the importance of coordination in megaprojects, given the multiple resources involved. They noted that coordination promotes collaboration through open communication among participants, thus addressing the complexity triggers. Ochieng and Hughes (2013) recommended continual communication among teams to manage complexity, with Dias et al. (2014) and Nguyen et al. (2018) advocating continuous planning to coordinate numerous participants and resources.

Following an in-depth analysis of the pivotal role of competence within complex contexts, the next section investigates existing research on aligning project strategies with complexity factors, aiming to enhance the efficacy of management practices.

2.7.2 Project Complexity's Impacts (Relationship C)

Based on the introduction, prior research has demonstrated that project complexity significantly impacts performance. Ma and Fu (2020) studied 16 mega-construction projects in China and found that project complexity significantly affects their success, with high complexity leading to lower project success rates. Similarly, Nguyen et al. (2018) emphasised the adverse effects of complexity on transportation project schedules and reiterated that complexity must be managed through resource scheduling. Bilgin et al. (2022) also highlighted complexity's detrimental impacts on performance, necessitating proactive approaches. These findings reinforce Relationship C by linking inadequate complexity management in mega-projects to poor performance.

Building on the evidence of the detrimental effects of project complexity, the following section explores the vital role of managerial competence in mitigating complexity challenges and proposes Relationship B in the framework.

2.7.3 Project Strategy and Complexity Management (Relationship A-B-C)

As established in previous sections, selecting appropriate project strategies is critical for successfully managing complexity and ensuring positive outcomes. Omar and Fayek (2016) proposed a neural network methodology to identify competencies and improve performance. However, they noted that traditional strategies in developing countries often fail to build the requisite competencies during mega-construction projects. Other studies have emphasised the development of strategies tailored to complexity factors. Nyarirangwe and Babatunde (2021) highlight the need for competencies complementing selected strategies. Dao et al. (2016) recommended identifying fundamental complexities before developing aligned management strategies (Kermanshachi et al., 2021).

Contingency management theory suggests that strategies should be adopted based on specific project characteristics and complexities. This provides the rationale for first identifying Nigerian mega-project complexity factors (Study α) to evaluate digital construction as a potentially aligned strategy to augment the critical competence identified in Study β. Research affirms that project strategies must directly address project complexities to enhance performance (Bosch-Rekveldt et al., 2011). The proposed framework integrates these findings by positing digital construction as a strategy to improve competence in managing the identified complexities.

Drawing upon the comprehensive literature review conducted in the preceding sections, which delved into the dimensions of complexity, the significance of competence, and the strategies employed, the ensuing discourse synthesises these critical elements to construct and substantiate the envisioned conceptual framework.

2.7.4 Building the Conceptual Framework

The preceding sections review the extensive literature on the key concepts of project complexity, managerial competence, and project strategies. This review demonstrated that project complexity can significantly affect the performance outcomes of mega-construction projects (Relationship C). It also highlights that project manager competence is critical in mitigating these impacts (Relationship B), with specific competencies required to address the structural and dynamic complexity factors. Additionally, project strategies must align with complexity elements in a project context to facilitate the effective management of complexity.

The conceptual framework integrates these findings by positing that adopting digital construction technologies can be an appropriate project strategy to enhance managerial competence in managing specific megaproject complexities identified in the Nigerian construction context. If confirmed through hypothesis testing, this finding suggests that digital construction can enable project managers to manage complexity more effectively and improve project performance.

This extensive literature review revealed substantive knowledge gaps that warrant further scholarly investigation. First, while studies have examined megaproject complexity, limited research has explicitly targeted the most salient complexity factors in the Nigerian infrastructure context (Sub-RQ1). Additionally, scant empirical work has identified project management competencies that are most critical for mega construction projects in Nigeria (Sub-RQ2). Finally, the potential of digital construction strategies to enhance project management competence amidst complexity still needs to be explored, presenting a promising avenue for research (Main RQ). This doctoral study aims to address these gaps through rigorous methodology by identifying fundamental complexities and competencies before evaluating whether implementing digital construction can augment competence in managing mega-construction intricacies. The next chapter outlines the mixed-methods research design structured to investigate these questions underpinning the conceptual framework.

Summary

Chapter Two extensively reviews three core domains: project complexity, competence, and digital construction. It establishes the significance of mega-infrastructure projects alongside the prevalence of complexity-induced underperformance, synthesising the limitations of prevailing strategies. The multifaceted dimensions of mega-construction complexity were explored, emphasising structural and dynamic complexity as pivotal constructs that require targeted competence. Diverse technical competencies identified as vital for complexity management were analysed, including communication, coordination, and planning. Traditional project management strategies were discussed, highlighting the potential of strategic digital construction approaches to address communication, planning, and monitoring amid complexity. Overall, this review integrates insights across domains, identifies research questions, and proposes an original conceptual framework focused on leveraging human-centred digital construction to enhance project management competence in megaproject complexity management. The next section comprehensively presents the rigorous research methodology employed to investigate the formulated research questions underpinning this scholarly undertaking.

Chapter 3 Research Methodology

This chapter comprehensively describes the research methodology employed in this study, outlining the protocols for data collection and analysis to address the research aim, objectives, and questions. Commonly used frameworks in scholarly research, such as Research Onion (Saunders et al., 2019) and Research Design Elements (Crotty, 1998), are often used to illustrate the adopted research methodology. This study used Saunders et al.'s (2019) Research Onion (Figure 3.1) to structure, design, and develop the research process, ensuring the reader can easily understand the methods employed. The chapter begins by discussing the initial layer of the onion, which pertains to research philosophy, and then progresses through the subsequent layers, providing detailed explanations of the researcher's decisions at each step. This research design showcases the evolution of thinking and demonstrates how the research questions were comprehensively addressed.

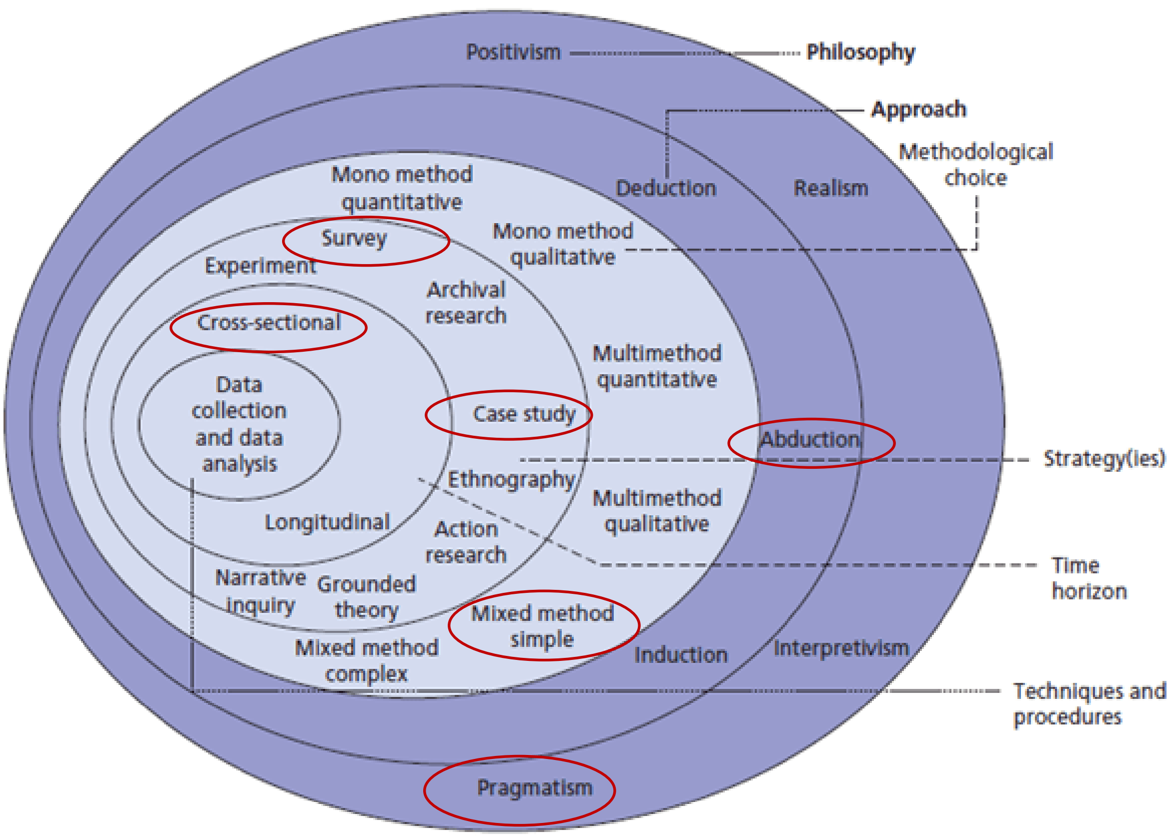

Figure 3.1 Saunder's Research Onion, and the Researcher's Choices (Saunders et al., 2019)

3.1 Philosophical worldview

Within research, a scholar's philosophical worldview fundamentally guides their actions and approaches. Academic discourse presents multiple perspectives for elucidating this worldview. Guba (1990) defined it as an interconnected network of beliefs that govern research endeavours. Neuman and Blundo (2000) adopt a broader view, describing it as an inherent philosophical assumption. Mertens (2019) characterised it as a paradigm, whereas Creswell et al. (2003) considered it a knowledge claim. According to Creswell and Creswell (2017), a researcher's worldview encompasses the general orientation of the world and the nature of the research, shaping their study and influencing knowledge generation (Saunders et al., 2019).

Furthermore, a researcher's preferred philosophical standpoint determines the appropriate research designs and methods to address their questions comprehensively. Guba and Lincoln (1994) assert that research philosophy is underpinned by three fundamental concepts: ontology, epistemology, and axiology. Ontology examines the nature of reality; epistemology delineates acceptable knowledge; and axiology evaluates the value of knowledge (Saunders et al., 2019). The following sections elaborate on the philosophical assumptions underlying the research approaches presented in Table 3.1.

3.1.1 Ontological Consideration

Ontology, as a branch of philosophy, examines the fundamental nature of existence and reality. In research, ontology refers to assumptions about the nature of reality and objects under investigation. Objectivism and constructivism represent two predominant ontological positions that influence research. Objectivism posits that social entities exist independently of actors, with society following fixed laws that explain phenomena. Conversely, constructivism contends that reality is shaped by actors' perceptions and actions, each with unique interpretations that are continually negotiated (Saunders et al., 2019).

Objectivism may seem suitable in this study's context, given the rule-governed nature of construction followed by all actors. A broad consensus exists that project manager competence is pivotal for project success, especially in complex mega-construction (International Centre for Complex Project Management, 2012). From an objectivist perspective, competence is instrumental to managing complexity. However, to fully comprehend the realities underlying competence and digital construction implementation in mega-infrastructure, researchers must immerse themselves in project managers’ natural environments. Given the limited existing narrative, this immersion is vital to explore the meanings individuals ascribe to these realities and to identify the prevalent complexity and competence factors (Saunders et al., 2019).

In contrast, Kapogiannis (2014) advocates a constructivist perspective to understand better the realities that project managers associate with complexity, competence, digital construction, and their environment. Given the multidimensional and dynamic nature of these concepts, this study aligns with a constructivist stance to comprehend the unique realities project managers ascribe. A researcher’s immersion is imperative for fully grasping and exploring these realities.

In conclusion, ontological assumptions significantly influence the research processes and outcomes. Objectivism and constructivism have distinct strengths and limitations. Constructivism is essential for understanding individual perspectives on complexity, competence, digital construction, and the environment. The evolving nature of these realities necessitates researchers’ immersion in project managers' natural environments to fully grasp and elucidate the associated meanings and factors.

3.1.2 Epistemological Consideration

Epistemology examines the nature of knowledge, including its acquisition, validation, and dissemination. A researcher's chosen epistemological stance significantly influences their research design, as it delineates acceptable knowledge forms in a field and guides the examination of phenomena. This study considers two predominant epistemological assumptions: positivism and interpretivism (Saunders et al., 2019).

Positivism is a philosophical theory that defines a generalised reality that illustrates a community's collective assumptions, values, and concepts. It assumes that phenomena are objective entities, independent of the researcher, that can be observed and quantified using appropriate tools (Creswell and Creswell, 2017). Positivist research often isolates the phenomenon carefully to enable objective capture of situations and consequences rather than antecedents (Creswell and Creswell, 2017). For instance, in examining Nigerian construction site complexity elements (objective one), a positivist approach may consider complexity as a quantifiable generalised reality described by specific measures. Here, the researcher is an uninvolved observer who neither affects the subject nor influences the complexity effects during construction. Their role is to scientifically measure a phenomenon's properties using tools, such as surveys, to generalise findings.

This study also examined the management of physical complexity. Complexity can be better assessed and understood by quantifying and measuring these dimensions and highlighting the importance of positivism in comprehending construction complexity through an objective and rigorous framework. Additionally, positivism emphasises the phenomena's objective observation and measurement to identify variable trends and relationships, capturing situations and consequences (Mertens, 2019). For objectives four and five, the researcher adopted a positivist approach, using surveys to statistically elucidate variable relationships, aligning with Teddlie and Tashakkori's (2011) view that positivists gravitate toward surveys for statistical explanation. The hypothesis formulation demonstrated the positivist orientation of this study in assessing concept relationships and quantitatively establishing data trends.

Nevertheless, positivism may present limitations in this research context, which necessitates understanding of how project managers' competence, digital tools, and challenges interact within the construction-site environment. This highlights the need for interpretivism, which seeks to understand phenomena from an individual’s perspective and to explore interactions among individuals and their historical and cultural contexts. It posits that reality is multifaceted and inseparable from context (Creswell and Creswell, 2017). This ideology suits objectives two and three, which aim to comprehend project managers' attitudes, behaviours, and internalised beliefs to elucidate competence factors and assess the influence of digital construction.

Furthermore, examining the behavioural dimension of construction project complexity management through competence assessment acknowledges an interpretivist epistemology that emphasises observing and analysing project managers' inherent characteristics and traits to fully understand their competence. As a human trait, competence can only be understood from megaproject managers' viewpoints, necessitating researcher immersion to capture distinct perspectives. Unlike positivism, this approach allows us to infer whether digital tools positively influence construction, which is critical in assessing the influence of digital construction on competence (objective three). It also addressed objective six, where participants stated the framework implementation opinions.

This study acknowledges the need for positivist and interpretivist perspectives by employing a pragmatic mixed-methods approach guided by the research questions. Pragmatism recognises that the most appropriate philosophical stance depends on the question, allowing diverse instruments (Saunders et al., 2019). Pragmatists contend that the research question determines the most suitable philosophical stance for a researcher because either positivism or interpretivism can be employed to address it (Saunders et al., 2019). Mixed methods integrate experiential, qualitative, and statistical data for a deeper understanding (Creswell and Clark, 2017), emphasising the problem and permitting multiple instruments, such as experiments, case studies, or surveys (Creswell and Creswell, 2017). Objectives one, four, and five utilised surveys, objectives two and three were guided by interpretivism, and objective six drew from both to assess the proposed framework's applicability. This approach enables the pre-emptive selection of the most suitable techniques to effectively address the research question.

This study's epistemological considerations emphasise a pragmatic approach that combines positivism and interpretivism. The mixed-methods design enables robust exploration for a comprehensive phenomenon understanding, which is crucial for doctoral research.

3.1.3 Axiology

As a research philosophy component, axiology concerns the value researchers assign to knowledge. Depending on the subject and method, it can be categorised as value-free or value-laden (Saunders et al., 2019). A value-free stance implies objective subject selection and methods, while a value-laden approach recognises that human beliefs and experiences influence the subject (Easterby-Smith et al., 2021).

The focus of this study is twofold. First, it delves into the value-laden realm by exploring project managers' experiences and opinions regarding using digital construction to enhance their competence. This acknowledges the subjective nature of their perspectives and the influence of personal beliefs. Second, it taps the value-free domain by aiming to understand complexity intensity and relevant competence factors during construction through an objective, quantifiable approach.

Consequently, this combined axiological approach aligns with the pragmatic philosophical stance. Pragmatism employs methodological pluralism and multiple forms of data for comprehensive understanding. Utilising both value-laden and value-free perspectives, the researcher recognises the need to consider subjective experiences and objective measurements to gain comprehensive insight, which is crucial for rigorous doctoral research.

Table 3.1 Research Perspectives on Management Comparison (adopted from Saunders et al. (2019)

	Positivism	Interpretivism	Pragmatism
Ontology: *the researcher's view of the nature of reality being*	External, objective, and independent of social actors	Socially constructed, subjective, may change, multiple	External, multiple, view chosen to best enable answering the research question
Epistemology: *the researcher's view regarding what constitutes acceptable knowledge*	Only observable phenomena can provide credible data, facts. Focus on causality and lawlike generalisations, reducing phenomena to simplest elements	Subjective meanings and social phenomena. Focus upon the details of situation, a0 reality behind these details, subjective meanings motivating actions.	Either or both observable phenomena and subjective meanings can provide acceptable knowledge dependent upon the research question. Focus on practical applied research, integrating different perspectives to help interpret the data
Axiology: *the researcher's view of the role of values in research*	Research is undertaken in a value-free way, the researcher is independent of the data and maintains an objective stance	Research is value-laden; the researcher is biased by worldviews, cultural experiences, and upbringing. These will impact on the research	Values play a large role in interpreting results, the researcher adopting both objective and subjective points of view
Data collection techniques mostly used	Highly structured, large samples, measurement, quantitative, but can use qualitative.	Methods chosen must fit the subject matter, quantitative or qualitative	Mixed or multiple method designs, quantitative and qualitative

3.2 Research Approach

The adopted research approach highlights the purpose of this study in developing or testing an existing theory. Three fundamental approaches are central, namely deductive, inductive, and abductive reasoning (Saunders et al., 2019). Deductive reasoning focuses on constructing and rigorously testing a theory, beginning with a theoretical framework to formulate hypotheses, and collecting and analysing data to draw inferences that support or refute these notions (Creswell and Creswell, 2017). This approach is often associated with quantitative methods, emphasising hypothesis testing and data quantification.

On the other hand, inductive reasoning recognises patterns within assembled data to construct theories that mirror identified patterns. It builds on human cognition and interpretations of sociocultural realms, allowing theory construction based on observed patterns (Creswell and Creswell, 2017). Inductive reasoning closely aligns with qualitative methods, emphasising multiple perspectives to understand human problems.

Here, pragmatism is appropriate for understanding project managers' competence during construction in Nigeria's under-researched context. An inductive approach is employed to comprehend this human problem from various perspectives and fill literature gaps (Yin, 2012). Additionally, observing managers in natural settings aligns with an inductive approach to gathering qualitative insights by exploring their experiences.

Examining the influence of digital construction on competence implies deductive reasoning. Consequently, an abductive approach that combines induction and deduction complements this study's pragmatic stance. Abduction allows for systematically testing hypotheses while considering inductive insights from observing project managers in natural settings. This study can comprehensively understand competence during construction by incorporating induction and deduction elements and systematically evaluating hypotheses using qualitative and quantitative data. This enabled a robust examination of the research problem.

3.3 Research Choices

This section addresses the methodological considerations for selecting appropriate data collection and analysis techniques. This research encompasses two fundamental methodologies: quantitative and qualitative (presented in Table 3.2). Quantitative methodologies involve numerical data and statistical analysis, whereas qualitative methods rely on non-numerical techniques (Creswell and Creswell, 2017). Furthermore, quantitative research often assesses hypotheses and makes accurate predictions. Here, adopting a quantitative methodology allows for testing hypotheses, validating the proposed framework, and effectively measuring complexity intensity during construction in Study α. This provides a structured means to quantify and analyse data against solely using project managers' qualitative narratives to quantify complexity that could be ambiguous (Saunders et al., 2019). As a multifaceted phenomenon, complexity necessitates a systematic, objective measurement and analysis approach that quantitative methodologies can provide.

Conversely, qualitative methodology enables a more comprehensive exploration of a subject (Creswell and Creswell, 2017). This study explores competence and digital tool application during construction from the perspective of project managers, providing a holistic understanding of their first-hand experiences in mega-construction projects in Nigeria. This methodology allows examining influencing factors, such as individual perceptions, attitudes, behaviours, and contextual and cultural factors shaping their experiences.

Saunders et al. (2019) identified multiple methodological approaches. Mono methods use a single data-collection technique and corresponding analysis, focusing on quantitative or qualitative methodologies. In contrast, multiple methods use several quantitative or qualitative techniques (multi-methods) or integrate them to complement each other (mixed methods) (Teddlie and Tashakkori, 2011). This study employed a sequential mixed-method design using distinct quantitative and qualitative approaches to address the research question.

According to Tashakkori and Teddlie (2003), using multiple methods provides more significant opportunities to address research questions and evaluate the trustworthiness of findings. Mixed methods combine strengths of both realms while mitigating weaknesses and enhancing confidence. The pragmatic philosophical stance adopted in this study emphasises the use of mixed-method research, which allows the researcher to effectively address the research question and produce more robust results (Saunders et al., 2019).

The mixed-methods approach aims to understand complexity and competence narratives, assess the impact of digital construction on competence, and empirically capture perspectives on using digital construction to manage complexity in Nigerian mega-projects. Thus, a mixed methodology is crucial for addressing the research question and effectively achieving the study objectives.

Table 3.2 Quantitative vs. Qualitative Methodology Differences

Attribute	Quantitative research	Qualitative Research
Common purpose	Test hypotheses or specific research questions	Discover ideas, with general research objects
Approach	Measure and test	Observe and interpret
Methods	Specific methods of chosen samples	Choose samples from individuals that are most likely to contribute
Data collection approach	Structure response	Unstructured and free form
Researcher independence	Uninvolved Observer	Intimately involved
Sample size	Large samples for generalisation	Small sample within natural settings

3.4 Research Strategy

The first objective of this study was to investigate complexity intensity during Nigerian mega-construction projects. Achieving this requires identifying an appropriate strategy to address the research question effectively. As Naoum (2012) highlighted, research strategy is the methodology for investigating this question. Table 3.2 depicts strategies researchers can use for exploratory, descriptive, or explanatory research, considering factors such as control over events and focus on contemporary or historical events (Yin, 2012).

According to Saunders et al. (2019), the research question, knowledge base, available time and resources, and philosophical worldview influence strategy selection. A survey approach was deemed the most suitable for understanding project managers' perceptions of complexity intensity during Nigerian mega-construction. This approach was also considered appropriate for determining whether digital construction could enhance competence in managing complexity and evaluating the proposed framework.

Surveys provide insights into a phenomenon's contemporary status (Fellows and Liu, 2015) and are helpful when researchers aim to generalise findings from a sample to a larger population using questionnaires or structured interviews in longitudinal or cross-sectional studies to quantitatively capture trends within a designated sample (Creswell and Clark, 2017). Surveys rely on statistical sampling principles in which sample information describes population characteristics (Kumar, 2018).

The survey strategy was chosen because it defines the variables of interest and ensures a well-defined scope, facilitating the generalisation of results. Despite potential drawbacks, such as limited in-depth scrutiny (Fellows and Liu, 2015), the surveys were deemed appropriate. Questionnaires were developed through extensive literature review and focus groups to ensure that theoretical expressions reflected actual practices (Naoum, 2012). Surveys also effectively study personal factors and explore relationships (Yin, 2012), aligning with the second objective of competence factors. A semi-structured questionnaire was used to gather numerical data and insights into competence factor relevance and associations. Surveys allow generalising the findings from a small sample to represent a broader population (Forza, 2002).

To assess the influence of digital tools on competence, researchers must be immersed in a natural mega-construction site setting. The case study method enables the investigation of a specific phenomenon within a real-life context, generating a rich record expanding on theoretical insights, unlike quantitative approaches, where participants express predetermined dispositions (Yin, 2012). Case studies are particularly suitable for in-depth exploration and understanding rather than confirming and quantifying variables, as in surveys (Kumar, 2018).

Additionally, case studies allow for the utilisation of multiple data sources, such as documentation, interviews, and observations. The third objective employed the latter. However, the gained flexibility from observation could be time-consuming. Although the findings may not fully represent Nigerian construction project managers' overall reality, they provide an in-depth analysis of particular context, serving as a foundational step in addressing contemporary issues such as utilising digital construction for complexity management (Yin, 2012).

To address the research questions and objectives of this study effectively, employing a research design that incorporates various methodologies aligned with the overall research philosophy is essential. Considering this, this study employs a mixed-methods research design, blending a survey and a case study strategy to gather cross-sectional data. This approach follows the pragmatic philosophical stance of the study, which emphasises the practical application of knowledge. The survey methodology allowed us to gather quantitative data from a large sample of project managers, providing valuable insights into their perspectives. Conversely, the case study technique enables us to better understand project managers' actual practices within their natural environment. Utilising these two approaches, we can achieve a comprehensive and nuanced analysis of the subject matter, thus enriching our understanding of the complexities involved.

Table 3.3 Elements of Different Research Strategies (Adapted from Saunders et al., 2019)

Name of strategy	Main Concerns	Required time and resources	Research questions applicable
Action research	- A specific context with a clear purpose	Requiring the involvement of the researcher, and the researcher needs to be devoted to all the actions throughout the process.	How
Ethnographic research	- Research process needs to be flexible and responsive to change	Requiring limited resources, the researcher has control of the time consumed	What, how, why
Survey	- Sampling - Mode of data collection - Validity	Requiring limited resources, the time consumed is not predictable	How, why
Case study	- Case selection - Reliability	In-depth investigation of research, requiring multiple kinds of resources, and it is time-consuming.	How, why
Experimental research	- Sampling - Validity	Required limited resources, the time consumed is not predictable	How, why
Grounded theory	- Category and coding - Theoretical sampling	Requiring limited resources, the researcher has control of time consumed	How, why

3.5 Research Design

The research design of this study adopts a mixed methodology approach to comprehensively explore and understand the critical complexity and competence factors in mega infrastructure construction, along with the influence of digital construction, to improve project delivery. It incorporates quantitative and qualitative data collection and analysis across six objectives and five stages (see Figure 3.2).

A literature review was conducted to identify an issue with project managers' competence in handling construction phase complexity in megaprojects, given inadequate prevailing strategies. The problem was clarified, and the research questions were formulated in Chapter 2. An extensive literature review of peer-reviewed journals and published books identified vital constructs. Multiple databases were searched, spanning 1996-2022, assessing article relevance. The most relevant articles were cited in eminent project management journals. The literature review in Chapter 2 establishes a conceptual framework aligned with the context in Chapter 1.

In Study α, the first phase of the second stage, the researcher aimed to identify and categorise salient complexity factors during mega-infrastructure construction in Nigeria, addressing the lack of focused studies. The factors were derived from the literature review and categorised based on emergent characteristics through a pilot study with academics and practitioners. While an extensive initial list emerged, the researcher recognised the importance of defining realistic, achievable goals that contribute to knowledge of construction complexity in Nigeria. Thus, an online quantitative survey determined the most impactful factors based on emergent behaviour intensity during infrastructure construction. The data were subjected to exploratory factor analysis to reduce factors while retaining significance and explaining interrelationships (Cattell, 2012). This phase achieved the objective of evaluating intensity, answering the first sub-question by delineating the most extreme Nigerian mega-construction complexity factors based on the opinions of experienced project managers. This study contributes to the knowledge of complexity during Nigerian mega-construction.

In Study β, the second phase of the second stage, semi-structured video conference interviews were conducted to achieve the second objective and sub-question two using a qualitative approach. This allowed for a deeper understanding of project manager perceptions, as participants had more reflection time (Hammarberg et al., 2016). Unlike questionnaires, interviews also enable the observation of participant demeanour (Cresswell and Cresswell, 2017). The findings in Chapter 5 highlight the most relevant mega-infrastructure construction competence traits in Nigeria.

In study γ, the third phase of stage two, a case study approach utilising direct observation, addressed the third objective discussed in Chapter 6. This provided practical and theoretical insights into digital strategy applications and their impact on competence during construction. The findings enabled a comprehensive understanding of digital construction within the conceptual framework, elucidating digital tools and project manager interactions. They formed the foundation to address this broad research question.

The third stage developed a complexity management framework based on key literature review relationships and Study α, β, and γ findings. The conceptual framework depicted critical element relationships with the hypotheses describing them. Focus groups with academics and practitioners evaluated the Study α and β factors, providing application insights to develop understandable sub-hypotheses defining the framework. This was crucial given the limited exploration of these relationships. Questionnaires administered online to project managers tested the hypotheses using inferential statistics, achieving objectives four and five and addressing the broad research question. Interviews in stage four validated the framework, enhancing reliability and achieving objective six. Finally, stage five presented the findings, contributions, recommendations, limitations, and future research avenues.

In conclusion, this research employed a pragmatic, mixed methods approach across multiple phases to thoroughly investigate the aim of exploring complexity, competence, and digital construction influence in Nigerian mega-infrastructure projects. The multifaceted design enabled a comprehensive examination by triangulating findings from diverse sources, including literature analysis, surveys, interviews, observation, and hypothesis testing. This integration of qualitative and quantitative techniques provided the necessary depth and breadth to elucidate the intricate dynamics involved in complexity, competence needs, and digital augmentation potential in mega-construction projects.

To further elaborate on the aligned research design and associated methods adopted to address the study aim, the next section delves into the specifics of the data collection and analysis techniques leveraged across the sequential mixed methods phases. This discussion supplements the research methodology overview by providing rationale regarding the tailored instruments and procedures employed to comprehensively gather and examine data from diverse sources to produce integrated findings that advance understanding of the core interrelationships under investigation.

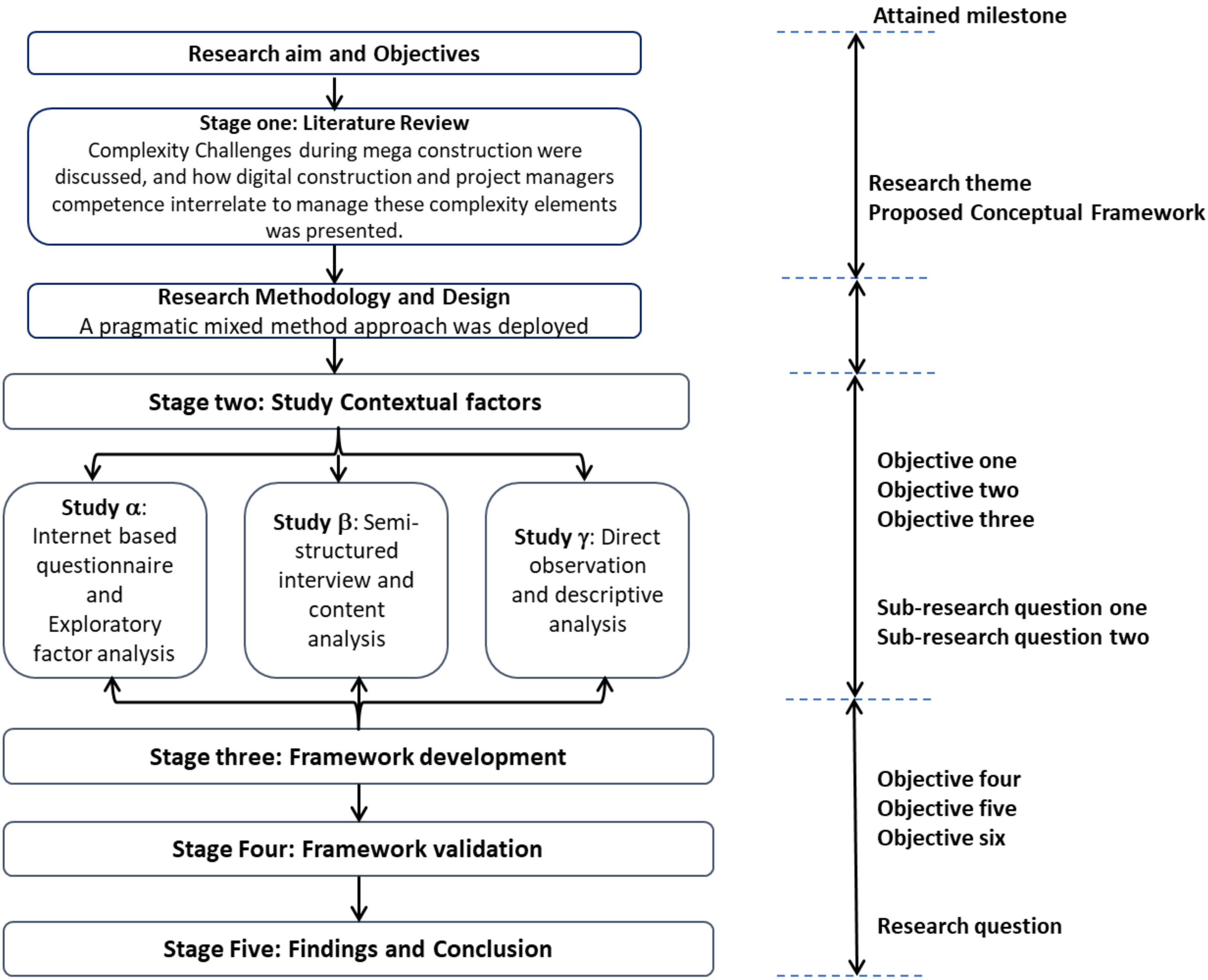

Figure 3.2 Adopted Research Design

3.6 Research Methods Adopted

3.6.1 Study α: Questionnaire Survey to Identify Prevalent Complexity Elements during Mega-construction

Given the limited existing research, the first objective is to identify the most significant complexity factors encountered by Nigerian mega-construction project managers. A five-stage approach was adopted to achieve this objective and answer the first sub-research question.

First, an exploratory literature review comprehensively identifies the commonly present mega-construction complexity elements. Second, a focus group discussion with ten experienced built environment professionals categorised these factors based on emergence characteristics, enriching understanding. Third, a survey questionnaire was designed based on literature review and focus group insights. Fourth, the questionnaire was administered online to the target population for efficient, large-sample data collection.

This research utilised an industry survey with an online questionnaire, analysing the resulting data quantitatively to provide valuable insights into salient Nigerian mega-construction complexity factors. The systematic five-stage approach for Study α is depicted in Figure 3.3, ensuring coherent and reliable findings. The methodology rigorously progressed through literature review, focus groups, questionnaire design, data collection, and quantitative analysis to enhance credibility and contribute to knowledge of complexity factors.

The research design systematically followed a multi-stage approach to identify and analyse complexity factors in Nigerian mega-construction projects. This rigorous methodology ensured coherent and reliable findings, addressing the first objective and sub-questions. This approach sought to contribute original insights into this under-researched area.

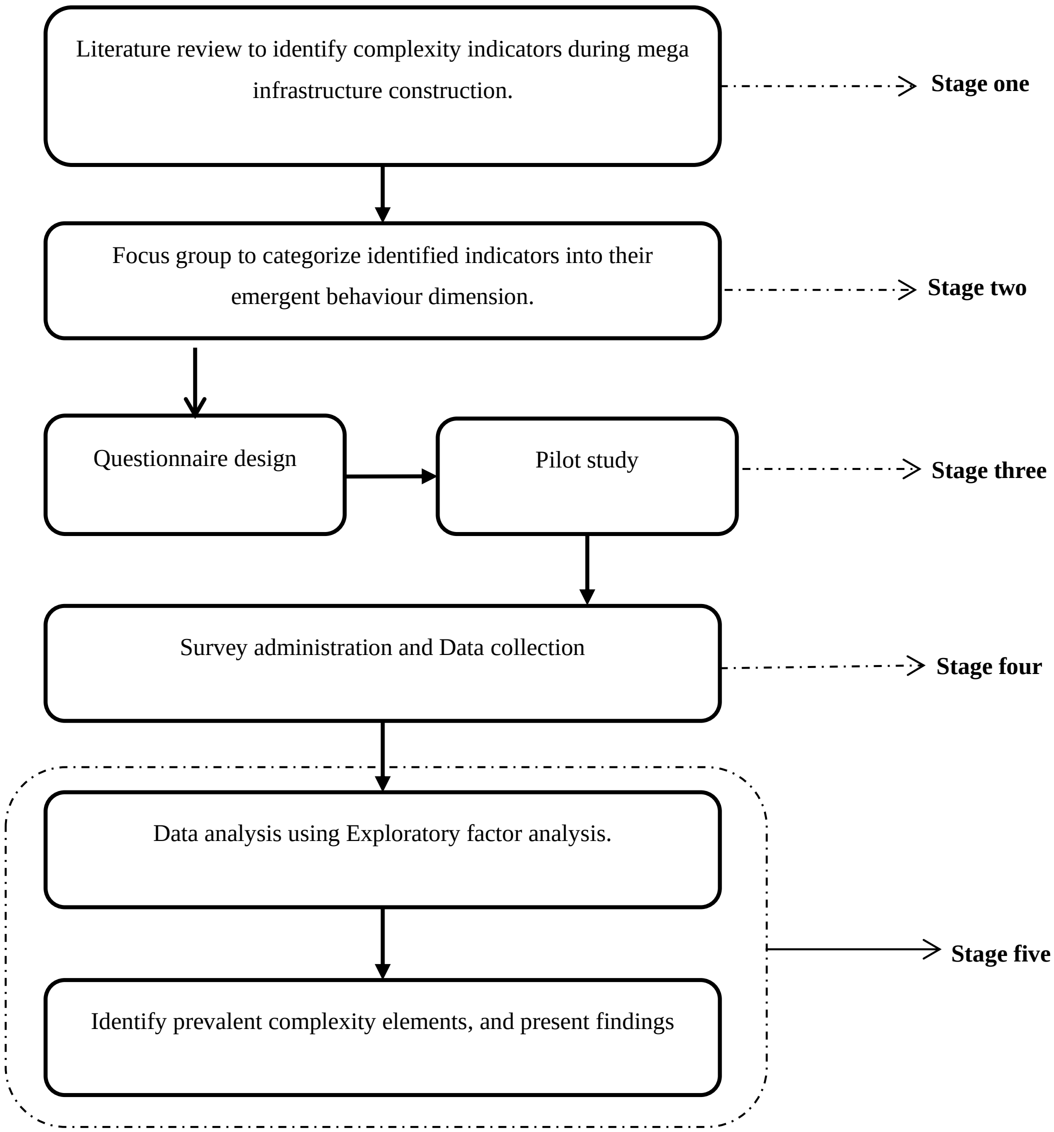

Figure 3.3 Five-stage Research Design

Stage One: Literature Review

The literature review method was first employed to collect mega-construction complexity elements. This allowed a thorough examination of the phenomenon, gaining insights from previous research, and identifying areas requiring further investigation (Fellows and Liu, 2015). Past research has examined entire project lifecycles holistically or implicitly, focusing on specific phases. However, this research narrowed its focus to the project execution phase, where construction management challenges intensifying complexity primarily manifest at construction sites (Chapman 2016). A literature review identified seventy-three typical construction site complexity elements, as detailed in Chapter 2. These were subsequently categorised based on emergent behaviour in the next stage, involving focus group discussion. This systematic approach enabled the comprehensive identification and categorisation of mega-construction complexity elements.

In summary, the literature review played a critical role in the research process by providing a solid foundation for further investigation and contributing to the development of the study's conceptual framework. The findings served as the basis for the subsequent focus group and survey questionnaire stages, establishing the context, background, significance, and relevance in addressing the research gap.

Stage Two: Focus Group

Focus group discussions have been recognised as a valuable methodological tool in research, allowing diverse opinions and reaching a consensus among a designated demographic (Saunders et al., 2019). Focus group discussions have addressed the literature gap concerning the lack of consensus on mega-construction complexity dimensions or measures in Nigeria. The goal was to provide valuable insights into existing knowledge. To ensure a robust sample, three built environment academicians and seven experienced field professionals participated, meeting the minimum recommended by Morgan (2012).

Based on the literature review, this study developed a nominal-scale questionnaire encompassing the seventy-three complexity elements identified. The questionnaire consisted of two sections. The first section required participants to express their agreement or disagreement regarding the applicability of each complexity element during infrastructure construction. The second section allowed participants to indicate the attributes of each complexity element's emergent behaviour by selecting either the structural (S), dynamic (D), or both (B) dimensions. This approach captured the different dimensions of complexity and provide a comprehensive understanding of the complexity of elements during construction.

Based on these findings, a questionnaire was designed for the next stage to establish which elements had the most significant impact during construction, allowing a focused investigation into specific high-impact complexity elements. Forty-nine prevalent mega-construction indicators were identified, with twenty-one structural and twenty-eight dynamic complexity elements, as presented in Table 2.2, Chapter 2. These findings contribute to the mega-construction complexity discourse by offering a nuanced understanding of distinct dimensions and prevalent construction phase indicators. The focus group results provided a solid foundation for further investigation and survey questionnaire development.

Stage Three: Questionnaire Design

In stage three, the questionnaire design captured project managers' perceptions of complexity element intensity based on emergent behaviour. The 55-question survey had three sections: Section 1 collected demographic data, and Sections 2 and 3 focused on structural and dynamic complexity indicators, respectively. The participants rated each element's contribution and uncertainty influence on an eleven-point Likert scale. A rating of 0 indicated no impact, whereas a rating of 10 indicated an extremely high impact. Similarly, in Section 3, participants were asked to select a value between 0 (no influence) and 10 (extremely high influence) for each complexity element, indicating the extent to which it led to uncertainty based on the predisposition of project managers.

A Likert scale adopted in prior complexity studies was used to ensure effectiveness and provide choices to enhance reliability and validity (Dao et al., 2017; Luo et al., 2017). A pilot study with focus group participants reviewed the format, wording, limitations, and completion time, eliminating repetitive, ambiguous, and redundant questions. The final questionnaire, which was refined based on feedback to ensure its relevance in capturing complexity perceptions, is included in Appendix A (Study α Questionnaire). The survey was tailored to effectively measure complexity opinions in mega-construction.

Stage Four: Survey Administration and Data Collection

To ensure a representative sample, simple random sampling and an online survey gave each targeted population member an equal selection chance, eliminating potential biases, and increasing reliability and generalisability (Sharma, 2017). This sampling method helped to eliminate potential biases and increased the reliability and generalisability of the data. The survey was administered via Qualtrics to 211 project managers registered in the Federation of Construction Industry (FOCI) database working on mega-infrastructure projects (N=211). The FOCI is known for maintaining an updated list of approved large construction contractors in Nigeria, making it a reliable source for identifying potential participants.

Online data collection was chosen for its cost-effectiveness, wide reach, and higher response rates than mail or in-person approaches (Manfreda et al., 2008). Participants were allowed to decline participation, although it was challenging to determine the exact number of individuals who received the questionnaire. Of the 189 entries, a 90% response rate was achieved, which is acceptable for online surveys (Medway and Fulton, 2012). To ensure the reliability and validity of the data, responses were screened for partially completed entries using the listwise deletion technique. Listwise deletion is typically more suitable than pairwise deletion for factorial analysis because it provides consistent and accurate results. In listwise deletion, an entire record is removed if there is a missing value, ensuring the analysis is conducted on cases with a complete data set (Alisson, 2009). Listwise deletion screens partially completed entries, preferred over pairwise deletion for its consistent and accurate factorial analysis results (Peng et al., 2006).

Pairwise deletion, on the other hand, removes specific variables with missing values, potentially introducing inconsistencies and biases in the analysis (Kumar, 2018). This can challenge the ability to draw inferences for the total sample, as the analysis may only include a portion of the dataset, causing potential bias (Peng et al., 2006). Moreover, when data correlations are high, as in factorial analysis, listwise deletion produces more efficient estimates than pairwise deletion (Peng et al., 2006). Therefore, listwise deletion ensures reliable, unbiased, and robust results for factorial analysis (DeCoster, 1998). The analysis software was instructed to eliminate cases with missing variables before data analysis, which reduces bias and increases the generalisability of the findings (Alisson 2009).

In summary, simple random sampling and online administration enabled reliable and valid data collection from construction project managers. Listwise deletion ensured suitability for robust factorial analysis.

Stage Five: Analysing Survey Data and Presentation of Findings

In stage five, 142 completed questionnaires capturing forty-nine complexity elements were analysed using exploratory factor analysis (E.F.A) to categorise indicators into dimensions describing their emergent intensity during mega-construction. Although past studies used Delphi surveys, Covid-19 protocols made this approach impractical because of reliance on physical presence (Avella, 2016). Consequently, this study's mixed-methods design yielded reliable and valid results.

The study focused on the distinct nature of structural and dynamic complexity, as they emerge from the distinct aspects of mega-construction projects. Structural complexity is related to the physical attributes of the project, making it challenging to manage, whereas dynamic complexity arises from uncertainty and hinders project managers from making optimal decisions. Consequently, separate E.F.A analyses were conducted for each complexity dimension, allowing a comprehensive understanding of the underlying factors.

Because structural and dynamic complexity emerge distinctly, separate analyses were conducted for a comprehensive understanding. Exploratory factor analysis is widely used to identify underlying factors, determine variable similarities, and facilitate data interpretation through categorisation (DeCoster, 1998). Based on the findings, it classified complexity indicators by emergent behaviour impact level to provide in-depth knowledge, as applied in past construction studies. Nguyen et al. (2015) adopted this approach to uncover underlying relationships and classify project complexity in transportation projects. Similarly, He et al. (2015) categorised complexity using the E.F.A technique based on emergent intensity on mega-construction sites in China. Furthermore, Soewin and Chinda (2018) applied E.F.A to classify relevant performance measures in construction projects to enable managers to evaluate performance indicators on-site. These studies indicated the appropriateness of applying E.F.A in the current study context.

Listwise deletion met the minimum requirements, resulting in 121 and 117 sample sizes for the structural and dynamic complexity dimensions, respectively. The findings presented in Chapter 4 were published in a reputable journal, achieving the first objective, and disseminating insights to improve Nigerian mega-construction outcomes.

3.6.2 Study β: Semi-Structured Interview to Identify Pertinent Competence Factors during Mega-construction

The second objective involves identifying the most prevalent competence factors project managers consider pertinent during Nigerian mega-construction. A qualitative approach using semi-structured video conference interviews was adopted to achieve this objective and to explore managers' perceptions and opinions on relevant competence factors for understanding mega-construction. Semi-structured interviews enable deeper exploration of open-ended data, yielding detailed empirical evidence. This allowed observing participants' nonverbal cues to enhance transcription (Hammarberg et al., 2016). Compared to questionnaires, this technique captures project managers' opinions more effectively and provides in-depth information by combining quantitative and qualitative characteristics for comprehensive subject understanding (Hammarberg et al., 2016).

Although unstructured interviews offer deeper insights, their format risks straying from the research theme, inconsistent data, and inference challenges across numerous participants. They also tend to be time-consuming and unsuitable for cross-sectional research, as in this study (Fellows and Liu, 2015). On the other hand, structured interviews can be rigid and limit follow-up questions, which could provide further insight. Semi-structured interviews balance flexibility while maintaining focus and addressing unstructured and structured interview limitations (Wellington, 2015).

Relevant construction competence factors were identified from the literature review in Chapter 2. The interview protocol (Appendix B) guided data collection. Due to Covid-19, online video interviews were conducted to ensure accessibility within a minimal budget while reducing bias (Hammarberg et al., 2016). Although face-to-face interviews are preferred, online interviews capture non-verbal cues through recordings and careful review, enhancing transcription (Saarijärvi and Bratt, 2021). The recordings were carefully reviewed multiple times to identify non-verbal cues and changes in vocal tone, thereby enhancing transcription quality. Subsequently, recordings were deleted according to university ethics standards.

The interviews targeted construction project managers with mega-infrastructure experience. It begins with greetings and background information. Participation was voluntary, and withdrawal options were outlined. The competence context was explained, and participants were presented with literature-derived factors. Participants were asked to identify critical factors, explain their choices and rate relevance, and suggest the top seven pertinent factors based on their experience. They were also questioned regarding the observed mega-construction complexity changes over time.

A deductive approach incorporating literature and expertise to establish an explanatory framework was chosen over an inductive approach, which typically derives direction from data for exploratory research. This provided a focused, structured interview framework (Yin, 2012). Participants were encouraged to present accounts narratively to simplify the analysis by avoiding fragmentation and enabling coherent categorisation and coding. Transcribed data were organised to reflect opinions on the mega-construction competence narrative (Kvale, 1996).

The participants were recruited via emailed FOCI invitations. A virtual interview link was provided based on interest. The interviews were recorded on a mobile device with consent and named based on their affiliation. Recordings were transcribed and analysed to provide a comprehensive competence factor narrative.

Qualitative Analysis

This section provides a detailed explanation of the data transcription and analytical techniques employed in this study. An accurate and systematic transcription of interview conversations is essential for conducting a comprehensive analysis. Transcribing involves meticulously converting spoken words into written text, ensuring that the nuances and intricacies of the participants' responses are captured. Furthermore, the chosen data analysis technique is introduced, outlining the methodology employed to derive meaningful insights from transcribed data. This section emphasises the significance of these steps in the research process as they facilitate the transformation of raw data into valuable findings. This underscores the importance of carefully analysing the transcribed data to uncover patterns, themes, and trends, contributing to a deeper understanding of the research topic.

Data Transcription

The qualitative interview data were transcribed using Microsoft Word 2016's voice recognition "dictate" feature to transform verbal communication into textual records, preserving participants' precise words. This technology was chosen based on recent advancements demonstrating its effectiveness for qualitative data transcription versus time-consuming, error-prone methods such as fee-based typists or manual transcription (Vindrola-Padros and Johnson, 2020). Voice recognition mitigates issues, such as omitting non-verbal cues that persist with other methods (Saunders et al., 2019).

During transcription, the researcher thoroughly reviewed recordings to familiarise themselves with the content and capture nuances in tone and non-verbal cues, significantly improving accuracy (Saunders et al., 2019). Additional steps were taken during the interviews to enhance quality. The researcher recited each question title multiple times before participant responses, ensuring accurate data classification and easy identification, particularly for scaled questions. This proactive interview approach improved transcription accuracy and organisation.

Post-transcription using "dictate”, the researcher meticulously scrutinised the data against the original conversation to correct errors and ensure fidelity, which is crucial for robust analysis (Chu, 2017). These rigorous measures aim to achieve high accuracy and reliability in transcriptions.

Data Analysis

Qualitative data analysis commenced by summarising transcribed recordings into concise statements, capturing the essence of the interview and highlighting central research considerations (Mann, 2016). Summarisation aimed to identify emergent themes and patterns more easily by condensing data (Mann, 2016). This technique was chosen based on the structured interview questions already categorised by underlying themes to capture project managers’ experiences regarding mega-construction competence.

Some scholars caution that categorising and coding transcribed data can compromise integrity, instead advocating summarisation and verbatim presentation as an analysis foundation (Saunders et al., 2009). This aligns with narrative analysis, focusing on chronologically ordered experiential accounts that reveal interconnected meaningful events (Coffey and Atkinson, 1996). In this study, participants selected critical factors from a literature list, explained relevance, rated factors, and suggested salient factors. The structured interview design meant that the collected data were already appropriately categorised, requiring only summarisation to construct the competence development narrative.

Narrative analysis explores relationships and interpretations in accounts, obviating further categorisation and thematic analysis (Saunders et al., 2009). It also elucidates complex phenomena that quantitative methods may miss. Narrative structural elements facilitate comparisons, enabling a holistic understanding of project managers’ beliefs, attitudes, values, and experiences regarding competence. However, narrative analysis risks subjectivity bias, which affects objectivity. Its limited narratives make generalising the findings challenging. This study incorporated a scale-based approach to gather participants' perspectives on crucial competencies to address this issue.

To present narratives, Coffey and Atkinson's (1996) framework was employed, providing a structural flow not necessarily in the exact sequence listed, which may recur in a single narrative.

This narrative structuring reduces text volume while expanding understanding as the narrative unfolds (Kvale, 1996), as observed in Table 5.1.

After conducting a narrative analysis, which shed light on why project managers deemed certain competences important, descriptive statistics were utilised to analyse and rank the relevance of competence factors, as well as demographic data from question three. The results were visually presented using graphs to provide quantitative data (Creswell and Creswell, 2017). Conversations were carefully transcribed, with Chapter 5 presenting study β findings. This achieved the second objective and addressed the second sub-question, contributing to the understanding of the significance of construction competence and highlighting specific factors that Nigerian project managers need to develop before venturing into mega-construction. The identified factors provide a clear delineation of the emphasised areas.

Table 3.4 Coffey and Atkinson's (1996) Framework for Narrative Structure Analysis of SQ two.

Structured Steps	In the current study
1. What the story is about. 2. What happened, to whom, whereabouts, and why? 3. The consequences that arose from this. 4. The significance of these events. 5. The final outcome.	This study aims to investigate project managers' opinions on competence during mega construction in Nigeria. In previous research, it has been highlighted that identifying the specific competencies required by project managers for each project type based on geographical location is crucial in managing complexity during mega construction and ultimately leads to improved project performance. By exploring the narratives of project managers, this study aims to contribute to the literature by identifying the relevant competencies that new entrants need to develop to navigate the complexities of mega-construction in Nigeria effectively. Moreover, this study will examine the efficacy of employing digital construction to augment project managers' competence in managing construction complexity. The findings will shed light on the effectiveness of digital construction as a competence enhancement strategy and provide insights for practitioners and policymakers in the construction industry.

3.6.3 Study γ: Case Study on Digital Construction using Direct Observation

The third objective examined the impact of digital construction on project management competence during Nigerian mega-construction. While Chapter 2 reveals the prevalent digital tool use in large construction projects, a significant gap exists regarding its application within the Nigerian context. An exploratory case study was conducted to monitor project managers' roles and digital tool engagement at Nigerian sites. The case study approach enables an in-depth exploration of a specific event, allowing the researcher to delve into digital construction on mega-construction sites (Yin, 2011). The case study approach allows the researcher to derive meaningful inferences from small, relevant samples when accessing numerous mega-sites may be challenging (Fellows and Liu, 2015).

Using case studies, researchers can extensively examine phenomena using various methods such as documentation, interviews, observation, and artefact analysis (Yin,2012). This study aims to understand digital construction deployment in Nigeria and its influence on project managers' competence. Thus, direct observation was deemed most suitable for collecting data without unduly intruding on the participants or introducing an interview bias regarding digital tool use (Yin, 2011).

During data collection, the researcher carefully observed manager-tool interactions on-site, ascertaining how the tools facilitated role performance and complexity management without active participation. Direct observation was chosen to collect data unobtrusively, minimising the risk of bias. Structured techniques define systematic observation protocols (Saunders et al., 2009). Site selection required a minimum of two digital tools. Consent letters outlining the intent for random observations were sent to numerous FOCI-registered sites. Nine sites were selected based on megaproject conformance and accessibility (Table 6.1). Consent helped address ethical concerns regarding observing human subjects (Kumar, 2018).

The researcher closely observed and listened to the managers and documented instances of digital-tool integration. At least five working days were spent at each site, and records were maintained through diaries and videos to facilitate transcription. The findings of this research phase were presented at the European Conference for Computing in Construction to accomplish the third objective. Observations provided valuable insights into digital construction applications in Nigeria and their impact on manager competence enhancement within mega-construction sites.

3.6.4 Framework Development and Validation: A Practical Complexity Management Approach

The sixth objective involved validating the proposed complexity management framework to enhance the performance of construction projects. Rigorous data analysis of the first three objectives was conducted to identify key complexity management themes related to digital construction. This enabled the comprehensive achievement of the fourth and fifth objectives, culminating in a proposed framework for project manager application during large-scale construction (objective six). The practical applicability of the framework in real-world contexts was systematically evaluated.

This study was conducted in five stages: First, the proposed conceptual framework (

Figure 2.5) was assessed to ensure that the key interrelationships reflected actual mega-construction practices. Second, a questionnaire was designed. Third, a data collection protocol was established. Fourth, the data analysis technique was delineated. Finally, a conceptual framework evaluation is discussed as follows.

Stage One: Assessing Key Themes and Framework Development

A comprehensive literature review initially highlighted the necessity of reducing complexity for optimal project management, emphasising competent project managers as vital components. The implementation of appropriate strategies to enable the effective management of complexity was identified to be essential. Chapter 2 presents the identified factors interrelationships and generalises shared themes.

An industry survey revealed that the structural complexity in construction projects stems primarily from scope, task difficulty, rigid sequences, and multiple locations. Dynamic complexity arises from the project duration, methods, methodological uncertainty, and interdependence. A qualitative study identified crucial competence, such as communication, planning, coordination, decision-making, information management, and problem-solving, which are indispensable for comprehensive complexity management during mega-construction. Figure 2.5 illustrates the relationship between managing complexity and mega-construction projects.

Sub-hypotheses were derived from the proposed conceptual framework hypotheses to further explore these core interrelationships, assess the framework, and address the fourth and fifth objectives and the broad research question. The sub-hypotheses were crucial for shaping the final survey questionnaire design.

The questionnaire was created through a collaborative pilot study with ten built environment professionals, including three academics and seven construction managers, meeting the ten-participant threshold. Based on the findings of Studies α and β, the focus group enabled in-depth exploration, allowing participants with similar demographics to provide new insights and identify literature-application connections (Morgan, 2012). Focus groups also aid hypothesis development, likely supporting data interpretation within a research theme (Morrison, 1997). This study identified the main broader competence factors from the literature, aligning with qualitative findings. The pilot study ensured that theoretical insights reflecting interrelationships were proposed at the subfactor level to reflect real-world practice.

The researcher presented the conceptual framework concepts and previous chapter findings at the start of the pilot study. Participants appreciated the highlighted interrelationships, indicating the complexity of management strategies during mega-construction. Drawing on the conceptual framework and study inferences, the researcher identified key theme relationships and presented constructs highlighting sub-hypotheses defining the final survey instrument for objectives four and five.

Study β identified team development as the seventh most relevant competence factor. However, because of the limited studies explicitly highlighting team development for complexity management, alongside focus group discussions indicating that it falls under specialist subcontractors' daily worker training purview (Kaskutas et al., 2013), this study refrains from considering it as a critical component moving forward. In mega-construction, reliance on specialists for team development is widespread (Akintan and Morledge, 2013), making it ubiquitous. These factors led to a decision to exclude it as a critical component.

While focus group findings may not be generalisable (Saunders et al., 2019), the discussions enhanced the study by providing in-depth insights into its concepts. This strategic approach ensured the questionnaire was valid and reliable for data collection.

Stage Two: Questionnaire Design

The questionnaire consisted of two distinct sections. Section one assessed project managers' perceptions of digital construction's impact on complexity management during construction using a seven-point Likert scale. This allowed participants to express their degree of agreement effectively. Section two gathered demographic and digital construction background information via categorical scaling. Project managers also indicated digital construction's significance level for competence on an eleven-point Likert interval scale from 0 (no significance) to 10 (utmost significance). The eleven-point scale enabled comprehensive responses aligned with common human psychology, preferring to rate responses on a scale of 1 to 10 (Wu and Leung, 2017).

The Likert scale used in this study was based on its applicability in previous research. Ahn et al. (2017) employed a five-point scale to investigate the influence of an interface management approach on the management of construction complexities. Mirza and Ehsan (2017) utilised an eleven-point scale to measure construction stage impact. These results demonstrate the efficacy of Likert scales in examining pertinent construction and complexity factors.

To guarantee the quality of the survey instrument, a meticulous review eliminated redundancy, ambiguity, and repetition to ensure quality. The Introduction explains digital construction and defines other terminologies. Participants lacking digital tool experience or exposure to multiple tools were instructed not to participate in the study. By implementing a well-designed and validated questionnaire, this study aimed to collect valuable insights into project managers' perceptions of the influence of digital construction on management competence to curtail complexity. Clarity and diligence were crucial for eliciting precise, informative responses.

Stage Three: Survey Administration and Data Collection

An online questionnaire empirically analysed the influence of digital construction on project management competence. Online surveys provide wide participant accessibility and convenience, enabling larger and more diverse data gathering (Manfreda et al., 2008). Additionally, online surveys provide cost-effectiveness by eliminating paper materials and reducing administrative costs. Online platforms also facilitate rapid survey creation, distribution, and global reach, making them suitable for time-sensitive research (Kumar 2018).

A total of 141 project managers participated, indicating an agreement on the influence of digital construction on management competence in managing complexity. Homogenous sampling ensured that participants had similar relevant characteristics when examining competence influences (Sharma, 2017). The online questionnaire, reflecting the developed hypotheses, was administered to 211 FOCI-registered project managers (N=211). FOCI have an updated approved contractor list. Data were gathered via Qualtrics from January to May 2021 and distributed through email and conferences, although tracking the recipients was difficult. However, the 72% response rate exceeded typical online survey expectations (Medway and Fulton, 2012).

Partially completed entries were screened, leaving 141 project manager (n) samples representing the population (N). Listwise deletion handles missing values by removing incomplete entries, thus supporting consistent and unbiased results (Alisson, 2009). This technique is preferred over pairwise deletion, which introduces inconsistencies due to varying missingness (Kumar, 2018). Missing data can challenge population inference, analyse only a dataset portion, and potentially cause bias (Peng et al., 2006).

Considering FOCI's meagre population (N=211), *Equation 1* determines whether the sample represents mega-project managers while minimising Type I error and ensuring significance. This method commonly estimates small, finite population intervals (Rea and Parker, 2014) by calculating a confidence interval to estimate the population proportion confidently. It accounts for the sample proportion and population size, providing insights into population characteristics. Importantly, it applies specifically to small finite population intervals (Rea and Parker, 2014), where:

$$\boldsymbol{n = \frac{Z_a^2\, s^2}{ME_i^2 + \frac{Z_a^2\, s^2}{N-1}}} \quad \text{……………} \textit{\textbf{ Eqn. 1}}$$

Z_a = 1.6558 at 95% confidence level

ME= Margin of error of 5%

***N* =** General population of 211

***s* =** Standard deviation of 1.004

The equation established a 95% confidence level for a sample size of 137, aligning with Raosoft’s online-generated suggestion (Raosoft, 2021).

Stage Four: Analysing Survey Data and Presentation of Findings

Following the data collection process, inferential statistics were employed to analyse the collected data and assess the hypotheses. Specifically, a one-sample t-test examines whether the sample mean aligns with or deviates from a hypothesised relevance value (De Winter, 2019). The one-sample t-test considered the sample response to depict the general population precisely. Its use here affirms that the sub-hypotheses, formulated based on pilot study participant-educated guesses, accurately represent the opinions of FOCI-registered project managers on digital construction. Given that managers have distinct digital construction perspectives, the one-sample t-test is suitable because it assumes that the dependent variable has a normal population distribution with independent data points (Rochon and Kieser, 2011). This strengthens the theoretical depiction presented by the focus group, reflecting field realities.

Although smaller samples are typically recommended for t-tests, recent studies suggest that larger samples can also be used when the degrees of freedom exceed 120, as the critical t and z effectively coincide, making the t-test applicable for larger samples. Hence, its use is justified (Rea and Parker, 2014). However, a constraint is the assumption of normality of the sample data for parametric tests. While arguments exist regarding the necessity of normality, robust parametric testing can mitigate non-normality effects (Rochon and Kieser, 2011). This supports using the one-sample t-test for analysing questionnaire Q3, while descriptive statistics, graphs, and tables address Q1 and Q2, providing an overview of the demographic data.

In testing Hypothesis 1, precisely, any value $0 < x < 1$, where x represents the value that digital construction does not influence project management competence, and $1 < y < 10$, where y represents the value that adopting digital construction augments project management competence. The researcher accepts any value where $y \geq 5$, with a hypothesised test value of 5 for the one-sample t-test, indicating an essential level of influence. The null hypothesis is rejected if the calculated t-value of $y \geq 1.6558$ (one-tailed critical t at the 95% confidence level) and if $p < 0.05$ α, indicating that the findings are statistically significant and not due to chance or sampling errors.

Similarly, for Hypothesis 2, any value $0 < x < 1$, where x represents the value that digital construction does not augment project management competence in managing construction complexity. In addition, $1 < y < 7$, where y represents the value that digital construction augments project management competence to curtail complexity during construction. The researcher accepted any value of $y \geq 4$, with a hypothesised mean value of 4 for the one-sample t-test. The null hypothesis was rejected if the calculated t-value of $y \geq 1.6558$ (one-tailed critical t at the 95% confidence level) and if $p < 0.05$ α level, indicating statistical significance and accurate representation of the general population (*N*).

For Hypothesis 3, a correlation analysis was used to examine the variable relationships. Pearson's correlation coefficient was used to assess the strength and direction of the relationships between digital construction influence and each construct used in sub-hypothesis development for each competence factor. Given that sub-factors measure specific aspects of the main factors from the literature, they must correlate to establish a reliable measurement of the main factor, ensuring that both measure the same theme (Hair et al., 2010). Testing the key subfactor-main factor relationships provides a crucial understanding of their importance and impact. Strong relationships supported the subfactor genuineness, leading to null hypothesis rejection.

Multiple regression was used to assess the overall competence factor relationships with digital construction influence, providing a holistic understanding of competence enhancement. Although structural equation modelling (SEM) offers statistical power for analysing complex relationships, it was unnecessary given the conceptual framework's more uncomplicated relationships. Positive construct relationships indicate digital construction competence enhancement in complexity management. Overall, the positive relationships confirmed the augmentation of specific competence.

Rather than using the best fit or regression line, Pearson's *r* alone provides a more defined relationship strength and explanation (Rea and Parker, 2014). The strength of the relationship between Pearson's r and regression was interpreted using the gamma coefficient (Table 3.5). Pearson's *r* statistical significance was determined using a t-test for significance, as presented in the finding's table, with significance determined when $t \geq 1.9776$ two-tailed critical t. This comprehensively addressed objectives four and five. The vital regression output findings were also presented to demonstrate robustness (Rea and Parker, 2014). *The F ratio in the table indicates that if a scatter plot is depicted, the regression line would be fit for predictive purposes and that a relationship exists between the variables. The coefficient of determination (r^2) highlights how well our sample data fit the regression model (goodness of fit) and explains the percentage variance of the dependent variable explained by the independent variable.*

Table 3.5 Pearson's *r* Coefficient Interpretation (adopted from (Rea and Parker, 2014))

Measure	Interpretation
0	No association
0.01 – 0.09	Negligible association
0.10 – 0.29	Low association
0.30 – 0.59	Moderate association
0.60 – 0.74	Strong association
0.75 – 0.99	Very strong association
1.00	Perfect association

Overall, this rigorous and systematic approach to hypothesis development, survey design, data collection, and analysis has contributed significantly to advancing construction project management knowledge by developing a practical framework for project managers to manage complexity and improve performance.

Stage Five: Evaluating the Framework

The evaluation of the Complexity Management Framework focuses on assessing its effectiveness from the industry's perspective. A systematic methodology involving questionnaire formulation, practitioner interviews, and meticulous data analysis was used to evaluate the utility. In evaluation, efficacy is vital, quantifying how well-predefined goals are met and identifying factors that hinder or facilitate achievement (Kumar, 2018).

The evaluation examined the questionnaire design and rigorously assessed its efficacy across two key dimensions: clarity and applicability. Clarity analysis investigates how well the framework outlines an industry-specific solution, aligns it with construction needs, and encapsulates essential requirements. Applicability examines user-friendliness, utility, and robustness. This exhaustive analysis is essential for determining the pragmatic viability (Wellington, 2015).

The questionnaire contained 12 carefully formulated questions in three sections (see Appendix E). Each section incorporated open-ended statements and 1-5 Likert scale ratings, constituting a refined measurement tool. Section one commenced the evaluation by eliciting insights into evaluators' roles, responsibilities, and experience. Section two reviewed the clarity across solution delineation, needs alignment, and requirement satisfaction. Finally, section three examined applicability through six questions inspecting user-friendliness, utility, and strength.

In addition, two open-ended questions elicited suggestions to inform refinements and gauge the intention to use the framework on active sites. Following the questionnaire design, structured interviews were conducted with project managers from earlier interviews and focus groups, either face-to-face or virtually, based on availability. This method ensured unbiased opinions and allowed for collecting detailed, unanticipated information. Questionnaires may impede framework understanding, whereas structured interviews enable information gathering beyond the initial research scope. Hence, the rationale for opting for structured interviews.

During the interviews, project managers completed an evaluation questionnaire and explained the responses as needed. Six evaluations involved returning and two new practitioners, enabling broader applicability testing. The evaluator’s commentary and suggestions underwent a meticulous review to inform enhancements. Subsequently, descriptive analysis compiled the findings by reviewing responses and quantifying and presenting the data in suitable tables and charts. Based on these recommendations, further Complexity Management Framework refinement was implemented. Section 8.2 compiled and presented the evaluation findings and results. This invaluable evaluation opportunity appraised the efficacy of the proposed framework through an industrial lens. These findings will drive ongoing refinements, thereby enhancing the viability of project managers in addressing complexity.

3.7 Target Population Sample

The primary focus of this research study is to examine project managers who possess extensive experience in the construction of large-scale infrastructure projects, commonly referred to as "mega" projects. In this study, megaprojects are defined as those with a budget exceeding $1 billion or projects that constitute a significant proportion of a nation's GDP. Data were obtained from the Federation of Construction Industry (FOCI) database to establish the sample frame for this study. The FOCI serve as the representative body for construction companies in Nigeria and maintains an updated database of approved construction contractors involved in megaprojects within Nigeria and globally. This database proved valuable in identifying potential participants in this study.

Established in 1954, FOCI serves as the representative body for construction companies in Nigeria, advocating their interests and safeguarding their rights (Federation of Construction Industry In Nigeria, 2022). The organisation monitors legislative measures affecting the industry, thereby ensuring fair and equitable treatment for its members. Over the years, FOCI has been instrumental in resolving issues such as outstanding debts owed to construction firms by the Nigerian government, and it continues to be a vital organisation representing national and international construction companies (Premium Times, 2018).

This study aimed to encompass all stages of the construction process, with a specific focus on the roles and responsibilities of project managers. Although the geographical location was primarily concentrated in Nigeria, it was not considered a limiting factor in this study. It is important to note that international construction companies often undertake mega-infrastructure projects, leveraging their expertise to become recognised leaders in their respective fields on a global scale. For instance, the Multiplex of Australia has gained recognition for constructing stadiums worldwide, provided funding is available. Similarly, Chinese state-owned enterprises are often at the forefront of low-income countries and offer cost-effective solutions for delivering large-scale infrastructure.

The data collection for this study involved engaging project managers who were registered members of FOCI and were currently involved in active construction sites, thus contributing to the qualitative aspect of the research. Simultaneously, the quantitative aspect focused on the general population of construction project managers within the FOCI. With FOCI's membership comprising 211 active project managers *(N)* and approximately 70 construction companies actively involved in infrastructure development in the region, this study benefitted from its diverse and extensive population. The study provides detailed information regarding the sample selected for participation from this general population, aiming to offer a comprehensive understanding of project managers' experiences and perspectives in the context of mega-infrastructure projects.

Overall, this study focuses on project managers with experience in mega-infrastructure projects. The sample frame was established using the FOCI database. This study aims to cover all stages of the construction process by considering both qualitative and quantitative data. This study benefitted from the diverse membership of FOCI, representing construction companies in Nigeria and internationally.

3.8 Ethical Consideration

In this study, adherence to ethical guidelines and considerations was paramount. Formal approval was obtained from the research ethics committee of the University of Nottingham for all the incorporated studies, ensuring that the proposed methods were ethically sound and respected participant rights. Several specific measures were taken during the data collection to maintain ethical standards. Participants received comprehensive details regarding confidentiality assurances for the questionnaire surveys, including no link between responses and personal identifiers. This safeguards privacy. Furthermore, participants were explicitly informed of their right to withdraw without repercussions. The collected data were used solely for academic purposes and were securely destroyed post-study, aligning with research ethics protocols.

Potential participants received consent letters for qualitative interviews outlining the study's purpose, involvement, and privacy protection. Interviews were conducted only after receiving affirmative responses and confirming voluntary participation. Diligent measures were taken to maintain confidentiality during interviews. Unique codes were used instead of identifiers to protect participants' anonymity. The interviews were securely destroyed upon the conclusion of the study, similar to the questionnaire data, which were only used academically.

For direct observations, consent letters were sent to construction companies that used at least two digital tools during construction operations. While participation was entirely voluntary, interested companies granted unrestricted site access for non-participant observation in a structured manner. The researcher ensured that no photos or videos could be captured to protect confidentiality. To mitigate potential biases such as the Hawthorne effect and social desirability bias introduced by the presence of the researcher on the construction site, the researcher posed as an intern, minimising behaviour changes in workers who were aware that they were being studied. This helped to maintain authentic on-site actions. This study employed rigorous ethical measures, such as questionnaires, interviews, and observations, to protect human subjects, ensuring compliance with the research ethics code of the University of Nottingham.

Summary

This Chapter outlines the coherent research methodology adopted to address the objectives of this study. Constructivism and pragmatism guide the abductive approach by using mixed methods. Surveys and case studies were logically selected to achieve the required depth and breadth. The aligned data collection methods included questionnaires, interviews, and observations. The five-stage design provided a clear progression that addresses all six objectives. Each study phase covers complexity factors, competencies, digital construction, hypothesis testing, and evaluation, which are methodically outlined. Sampling, analysis methods, and ethical considerations were detailed for each study, demonstrating meticulous planning. This chapter systematically maps philosophical assumptions to choices, strategies, methods, and designs to comprehensively address this aim through pragmatic mixed methods. Tables and figures visually aid this understanding. The research methodology established rigour through coherent and logical planning and choice alignment. The subsequent chapters discuss the findings of the mixed-methods approach used in this study.

Chapter 4 Study α – Physical Dimension

This chapter presents the research methodology adopted to address the knowledge gap regarding complexity assessment during the execution phase of Nigerian mega-infrastructure projects. The chapter begins by outlining the research objectives and questions to be addressed. An overview of the mixed-methods approach is then provided, encompassing the focus group, pilot study, questionnaire development, and data collection process. Next, exploratory factor analysis results for the structural and dynamic complexity dimensions are presented and discussed in detail. The tables and figures illustrate the statistical analyses that categorise complexity indicators into factors based on emergent intensity levels. Finally, the chapter summarises the significant findings from the data analysis, which identified complexity factors across four intensity groups: extremely high, high, moderate, and low. Overall, this chapter documents the systematic methodology adopted to address objective one and maps the progression from literature gap identification to the execution of the empirical investigation within the Nigerian construction context.

Objective One: *Evaluate the complexity elements that are most intense during mega-infrastructure construction.*

SQ1. *What are the most prevalent complexity elements that trigger challenges for project managers during mega-construction projects in Nigeria?*

4.1 Research Purpose

The inherent complexity of infrastructure development has been widely acknowledged, with multifaceted systems posing significant construction-phase challenges (Kermanshachi and Safapour, 2019). There is increasing recognition of the growing complexity and difficulty of infrastructure construction, adversely impacting project managers' effective management capacity (Ghaleb et al., 2022). This has precipitated scholarly consensus on the imperative for project managers to comprehensively understand complexity patterns during construction as an integral complexity management strategy component (Bilgin et al., 2022). Moreover, these studies highlight the need for geo-localised complexity element identification (Ghaleb et al., 2022).

Given this background, the lack of studies systematically identifying and categorising complexity based on emergent behavioural characteristics from a project manager's perspective, particularly within the Nigerian context, presents a significant literature gap. This understanding gap impedes the evaluation of the effectiveness of digital construction in enhancing project management competence in managing complexity. Dao et al. (2016) emphasised identifying prevailing complexity factors to effectively determine strategies to mitigate complexity impacts. Study α identified the prevalent Nigerian complexity elements, contributing to hypothesis construct formation and facilitating questionnaire development grounded in intense complexity factors. This enables the testing of the efficacy of digital construction as a project strategy.

4.2 Overview of Research Methodology

This chapter employs a mixed-method design to address the knowledge gap regarding complexity assessment during the execution phase of Nigerian mega-infrastructure projects. The scope encompassed project managers with prior mega-infrastructure experience registered in the Federation of Construction Industry (FOCI) database.

The methodology began by exploring the literature on complexity dimensions and frameworks. A review identified seventy-three pertinent construction site complexity indicators (Section 2.2). These indicators formed the basis for the focus group questionnaire using a nominal scale for participants to classify each as structural, dynamic, or both. The pilot study refined the questionnaire by eliminating redundancy, ambiguity, and repetition. The final questionnaire featured forty-nine complexity indicators: 21 structural and 28 dynamic.

The three questionnaire sections included participant demographics and the structural and dynamic complexity dimensions. The last two sections used a 10-point Likert scale to assess each indicator's impact or influence, chosen based on applications in prior construction complexity studies. Simple random sampling ensured equal opportunities for population selection. The questionnaire was administered online to 211 FOCI listed project managers. Of the 189 responses, 139 were selected for the analysis. Respondents had 6-30 years of experience, predominantly over 16 years, confirming their ample experience. However, no study has precisely defined the average construction project manager's experience, except the International Centre for Complex Project Management (2012), which defined an experience manager as one confirmed by his peer, outside the scope of this study.

Data analysis utilised Exploratory Factor Analysis (E.F.A) to categorise complexity indicators by emergent behaviour intensity during construction. E.F.A, widely used for discovering underlying variable influencing factors, is well-recognised in construction management. Its application aligns with studies by Nguyen et al. (2015), He et al. (2015), and Soewin and Chinda (2018), confirming suitability. This innovative approach of grouping complexity indicators by emergent behaviour provides comprehensive insights into the complexity of Nigerian mega-constructions. The following section presents the findings and discussion.

4.3 Results and Discussion

4.3.1 Structural Complexity Dimension

A total of 142 completed questionnaires were collected, encompassing forty-nine complexity elements: 21 structural and 28 dynamic. To perform factor analysis, listwise deletion satisfied the required minimum data, yielding a final sample size of 121 for structural complexity and 117 for dynamic complexity. A threshold of 100 cases or five samples per variable was achieved, which was considered adequate by prior research (Kline, 2014).

The structural dimension captures indicators that increase complexity from the project structural attributes. Exploratory factor analysis (E.F.A) was conducted using Principal Axis Factoring and oblique promax rotation. The individual item Kaiser-Meyer-Olkin (K.M.O) values were above 0.5 for sample sizes under 200 (MacCallum et al., 1999), and the overall K.M.O was 0.81, indicating appropriate data for E.F.A (Tabachnick et al., 2019). Bartlett's sphericity test ($\chi^2(210) = 3122.09$, $p < .001$) showed a patterned item relationship. Using a 1.0 eigenvalue cut-off, four factors explained 73.396% of the cumulative variance (Table 4.1), depicting loadings above the 0.40 significance level (Field, 2009). All elements loaded over a 0.40 significant factor level, except for density and technical expertise.

Additionally, established factors required 0.60 or higher Cronbach's alpha for internal consistency. This was achieved, and alpha if-item-deleted was collectively less than Cronbach's alpha (Nunnally and Bernstein, 1978). Each classified group's corrected item-total correlation exceeded 0.500, signifying high item consistency with the sum of the others (Table 4.1) (Cristobal et al., 2007).

Table 4.1 EFA Results for Structural Complexity Indicators

Element	Factor loading	Eigenvalue	CITC	Alpha if item deleted	Cronbach's α
Extremely high		10.930			0.931
Difficulty of task	0.792		0.797	0.919	
Rigidity of sequence	0.855		0.883	0.911	
Project scope	0.720		0.765	0.922	
Availability of skilled workforce	0.946		0.854	0.914	
Physical locations	0.749		0.711	0.927	
Multiple locations	0.846		0.762	0.923	
Site topography	0.519		0.706	0.929	
High		1.732			0.885
Type of structure	0.404		0.758	0.758	
Number of project participants	0.516		0.685	0.685	
Project budget	0.896		0.805	0.830	
Quality requirement	0.734		0.767	0.849	
Moderate		1.469			0.848
Structure height	0.545		0.505	0.854	
Numerous task	0.768		0.765	0.791	
High variety of task	0.425		0.669	0.815	
Project scheduling	0.561		0.624	0.828	
Construction method	1.037		0.743		
Low		1.283			0.870
Site perimeter	0.757		0.707	0.860	
Number of elements	0.837		0.826	0.752	
Required engineering hours	0.756		0.727	0.838	

Based on these results, the final structural instrument consisted of 19 elements classified into four factors: extremely high (F1), high (F2), moderate (F3), and low (F4) complexity intensity levels, per Thamhain's (2013) taxonomy (Figure 4.1). Each factor was captured over three elements, demonstrating the intensity with each indicator contributing to overall complexity from the project manager's perspective during mega-construction (Tabachnick et al., 2019). Factor complexity levels are discussed below.

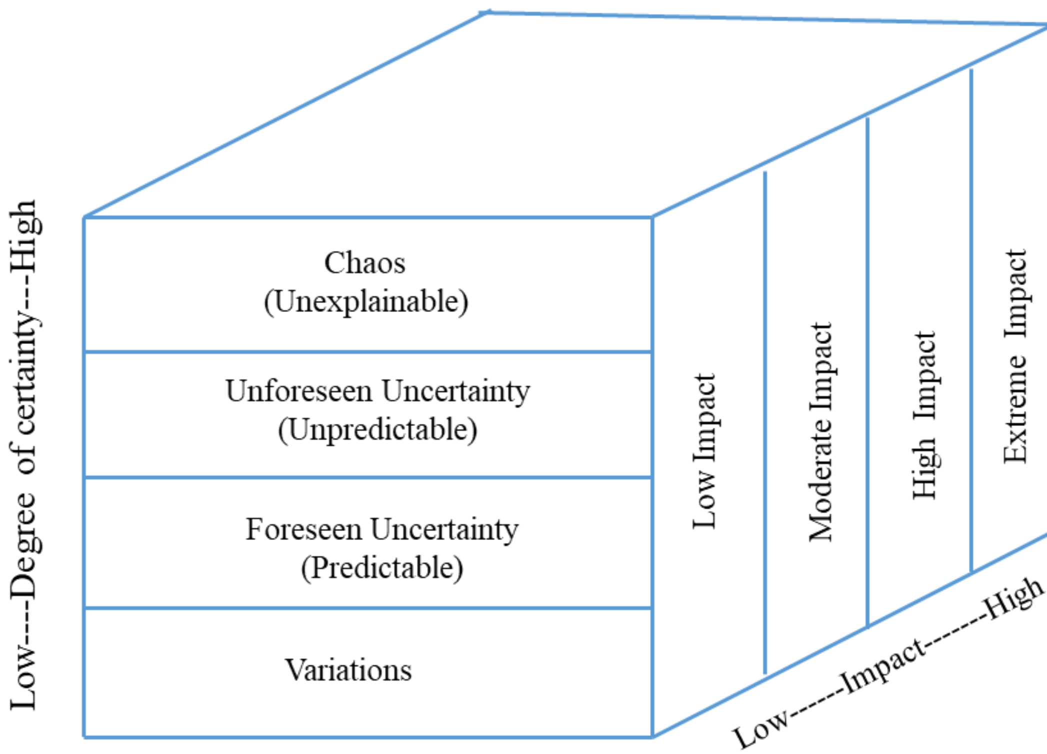

Figure 4.1 Thamhain (2013) Project Complexity Dimension based on Intensity

Extremely High Emergent Effect (F1)

The F1 dimension depicts elements requiring competent project managers to manage the intense complexity exerted during mega-construction (Remington, 2016). Such projects often involve high sequence rigidity, where complications can halt construction, known as a freeze, escalating complexity and challenges, as indicated in our survey.

Likewise, an expansive project scope compounds difficulties, easily overwhelming managers. This is intensified by the lack of a skilled workforce to execute tasks, deemed only a negligible contributor in the U.S (Kermanshachi and Safapour, 2019) but considered impactful in Nigeria, possibly due to automation and immigrant labour availability in the U.S. versus shortages in developing nations (Jarkas, 2017).

Additionally, physical location significantly influences complexity. Factors such as access, infrastructure, execution impacts, remoteness, and topography (Xia and Chan, 2012; Chapman, 2016) increase the structural and technical complexity, placing enormous strain on managers. This is further amplified if the project relies on other sites for inputs and resources, as corroborated by this study. Therefore, identifying excessively complex elements is critical, so managers can devise strategies to manage them effectively and improve the likelihood of successful mega-construction.

High Complexity Emergent Effect (F2)

The F2 dimension covers four key indicators contributing to project difficulty: infrastructure type and function, which determine participant numbers (Dao et al., 2017), anticipated quality requirements (Xia and Chan, 2012), and the overall budget (Bosch-Rekveldt et al., 2011).

With novel projects, larger budgets typically procure innovative technologies and specialist subcontractors. Insufficient funds escalate complexity, as managers operate under constraints. Even with ample funding, coordinating multiple participants and integrating modern technology introduces complexity in the time required to familiarise teams with methodologies.

Delivering near-defect-free projects presents monumental coordination, oversight, and workforce management challenges. Prior studies have emphasised these indicators as significant contributors to construction complexity (Dao et al., 2017). Our research elucidates the extent of their contributions. We suggest proactive strategies so that managers can better manage emerging complexities during construction (Nguyen et al., 2015). Understanding the likely difficulty elements enhances preparedness to mitigate their effects and improve execution prospects.

Moderate Emergent Effect (F3)

The F3 dimension covers five indicators that contribute to moderate complexity. One is the considerable height of structures, necessitating various equipment for elevated work, and escalating coordination complexity (Xia and Chan, 2012). The taller the project, the more diverse the tasks that need innovative methods and scheduling to manage the ensuing complexity (Gajić and Palčič, 2019). Our participants found that such factors moderately increase difficulty, suggesting that professionals acclimate to height through experience (Kermanshachi and Safapour, 2019).

Additionally, unfamiliar methods, such as prefabrication, can increase the complexity of building projects (Xia and Chan, 2012). However, our participants felt that this led to moderate infrastructure project complexity, possibly because of operational and sequence repetitiveness during construction. Moderate indicators can be managed through reactive strategies that enable optimal task oversight and coordination (Ochieng and Hughes, 2013). Intriguingly, these elements were unique to each project type. Understanding emergent behaviour helps managers develop competencies to handle mega-project challenges effectively.

Low Emergent Effect (F4)

The F4 category encompasses three elements with minor impacts: the site perimeter, engineering hours, and element numbers. Although identified as indicators (Mirza and Ehsan, 2017), studies have not specified impact levels. Increased size only slightly increases the construction complexity (Xia and Chan, 2012). In theory, more elements and engineering hours are aligned with larger project sizes. However, Ahn et al. (2017) found minimal interface management complexity despite more elements. During construction, element numbers can increase complexity, although elaboration is lacking (Gidado 1996). Our study addressed this gap and found that these indicators contribute minimally, possibly because of advanced technologies (Ofori, 2015). These nuances are essential to understanding the complexity of megaprojects.

4.3.2 Dynamic Complexity Dimension

Our questionnaire provided a project manager's viewpoint on the emergent behaviours of dynamic complexity, contributing to uncertainty and continuous change during mega-construction. Data were subjected to factor analysis using Principal Axis Factoring and oblique promax rotation. The individual and overall K.M.O. values exceeded 0.5 and 0.843, respectively, indicating adequate sample suitability for Exploratory Factor Analysis (E.F.A.). Bartlett's test ($\chi^2(378) = 3602.392$, $p < 0.001$) affirmed factor analysis utility for the data by suggesting patterned item relationships.

A 1.0 Eigenvalue cut-off extracted six factors, accounting for 75.196% cumulative variance (Table 4.2). A 0.40 factor loading significance level was set, with each extracted factor demonstrating over 0.60 Cronbach's α consistency. Furthermore, 'Alpha if item deleted' was collectively lower than α, except for project duration at 0.939 against 0.929. However, its 0.599 corrected-item-total correlation indicated high consistency with other indicators, surpassing the threshold of 0.400.

Table 4.2 EFA Results for Dynamic Complexity Indicators

Element	Factor loading	Eigenvalue	CITC	Alpha if item deleted	Cronbach's α
Chaos		**11.741**			**0.929**
Project duration	0.545		0.599	0.939	
Project tempo	0.915		0.849	0.909	
Construction method	0.809		0.837	0.911	
Uncertainty in methods	0.876		0.864	0.906	
Reliance on other projects	0.859		0.795	0.916	
Project teams' capability	0.837		0.820	0.913	
Unforeseen uncertainty		**3.380**			**0.910**
Uncertainty in scope	0.545		0.779	0.779	
Change in project scope	0.542		0.773	0.892	
Change in the project specification	0.664		0.844	0.874	
Inability to estimate accurately time and budget	0.849		0.763	0.893	
Quantity of information to analyse	0.745		0.722	0.900	
Foreseen uncertainty		**1.898**			**0.904**
Multiple project goal	0.545		0.631	0.901	
Variety of perspective	0.768		0.791	0.882	
Form of contract	0.425		0.673	0.895	
Disperse teams	0.561		0.690	0.893	
Multiple locations	1.037		0.779	0.883	
Multiple time zone	0.507		0.693	0.893	
Project drawings and detailing	0.877		0.763	0.885	
Variations		**1.573**			**0.855**
Geological condition	0.500		0.630	0.835	
Immediate project environment	0.438		0.626	0.837	
Plant deployment	0.654		0.610	0.840	
Regulations	0.708		0.747	0.807	
Lack of clear project goal	0.690		0.743	0.805	
Medium Variation		**1.368**			**0.696**
High number of goals	0.673		0.458	0.670	
Scope of work	0.871		0.601	0.493	
Ambiguity of scope	0.459		0.482	0.642	

Low Variation		**1.095**			**0.500**
Multiple project goal	0.455		0.355	--	
Number of information sources	0.575		3.335	--	

The final instrument yielded 23 indicators in four labelled factors after excluding F5 and F6 for low consistency and the 'deployment of workers' for loading below 0.400, possibly due to modern specialist subcontractor procurement (Rosli et al., 2018), where managers prioritise leads over workers (Rosli et al., 2018). Each factor had at least three indicators, named using Thamhain's (2013) uncertainty taxonomy, illustrating the perceived contributions to uncertainty and change during construction (Figure 4.4). The factors were chaos (F1), Unforeseen Uncertainty (F2), Foreseen Uncertainty (F3), and variations (F4) (Thamhain, 2013).

Chaos (F1)

F1 has six indicators that contribute to unpredictable alterations and performance impacts, representing unknown unknowns with unforeseeable planning phase impacts (Flyvbjerg 2017). Prolonged construction can decrease morale, culminating in chaos and negatively affecting tempo (Chapman, 2016). Uninterrupted resources influence duration and mitigate uncertainty, thus enabling effective oversight (Xia and Chan, 2012).

Construction methods and their associated uncertainty in Nigeria can precipitate chaos due to limited experience and proficient personnel availability, forcing reliance on other projects (Jarkas, 2017). This restricts governance, potentially hindering performance. Adopting real-time information structuring and dissemination methodologies is advocated along with further research (as in study α) to accurately identify prone projects during planning.

Unforeseen Uncertainty (F2)

F2 incorporates five unpredictable indicators discernible as instigating uncertainty and persistent change that managers grapple with to estimate occurrence frequency and associated scenario management during construction. The poorly defined planning stage project scope lays the groundwork for avoidable continuous rework, causing performance undermining through delays and cost overruns (Gajić and Palčič, 2019; Bosch-Rekveldt et al., 2011). Scope uncertainty prompts on-site design changes and specification alterations (Nguyen et al., 2015), challenging accurate timeframes and budget estimates, particularly without provisions to mitigate the situation.

Unpreparedness amplifies on-site uncertainty, inhibits coordination, and controls the alignment of objectives.

Reactive strategies (Maylor et al., 2008) can mitigate the dynamic complexity of the project scope. A comprehensive understanding of these elements would enable the identification of prone projects before site engagement.

Foreseen Uncertainty (F3)

F3 refers to the seven indicators contributing to constant changes and construction contingencies that can be managed with comprehensive plans. Their manifestation often causes delays and budget escalations (Thamhain, 2013). Multi-stakeholder goal management with contesting perspectives is unavoidable on mega-sites. The inability to clarify goals causes significant uncertainty, as the scope cannot be determined accurately (Gajić and Palčič, 2019). Reliance on multiple offsite locations exposes projects to uncertain degrees, which managers find difficult to ascertain. Virtual teams across time zones exacerbate dynamic complexity and restrict responsive decisions when they are unable to contact offsite teams.

Variations (F4)

F4 encompasses known indicators that induce manageable uncertainty through established tools (Remington, 2016). Primarily associated with requests for information and variations to manage uncertainty, managers expect these to arise from various sources such as the environment, unclear objectives, and plant deployment. Although they slow the project pace, they do not disrupt the construction output. These findings better equip managers to evaluate dynamic behaviour and identify elements warranting monitoring, promoting crucial competence development for effective management.

Summary

This chapter presents the findings from an empirical questionnaire-based survey of Nigerian construction project managers, addressing the knowledge gap regarding complexity assessment during mega-infrastructure project execution. The structural and dynamic complexity indicators were categorised using exploratory factor analysis based on extremely high, high, moderate, and low-intensity levels. This answers the first sub-research question on prevalent complexity elements. Regarding structural complexity – task difficulty, dispersed locations, site topography, and expansive project scope emerged as the top contributors to severe project challenges. In the dynamic complexity dimension, prolonged duration, inconsistent tempo, uncertainty in methods, reliance on other projects, and team capabilities increase uncertainty and change, precipitating chaos. Interestingly, contrary to expectations, worker deployment did not affect dynamic complexity. Project density and technical expertise also had a minimal impact on construction phase difficulties. These findings corroborate the viewpoint Dao et al. (2016) put forth that it is crucial to identify the key complexity factors when evaluating management strategies. Additionally, Nyarirangwe and Babatunde (2021) have emphasised the significance of project manager competence in assessing strategy efficacy. These findings have been incorporated into the sub-hypotheses and will be explored in greater detail in Chapter 7, where the competencies corresponding to these complexity elements will be identified, and the proficiency of digital construction in aiding project managers will be evaluated.

Chapter 5 Study β – Behavioural Dimension

Chapter Five presents findings from a qualitative interview-based study that examined project managers' competence requirements for infrastructure development in Nigeria. Semi-structured interviews were conducted with experienced infrastructure project managers to gather insights into the critical competencies for successful mega-construction projects. The chapter begins by outlining the research objective and providing an overview of the interview methodology. Next, the results were presented logically through participant profiles, responses to each interview question, quantitative competence rankings, and visual summaries. Using narrative analysis, this chapter presents these findings, providing the perspectives of project managers and a contextual backdrop to the interview process. This chapter summarises the findings of the study and highlights the key takeaways, paving the way for subsequent chapters of this thesis. This chapter documents a systematic process to address the study's objective of identifying project management competence factors pertinent to managing complexity in Nigerian mega-infrastructure projects.

Objective Two: *Identify the most prevalent competence factors project managers find pertinent during mega-infrastructure construction.*

SQ2. *Which project managers' competence factors must be augmented for successful infrastructure construction in Nigeria?*

5.1 Research Purpose

Project managers have been recognised as significant contributors to infrastructure project failure, especially in developing countries. Prior research indicates that such failures may stem from a misalignment between the competencies required for successful 21st-century infrastructure project execution and project managers' actual skills (Roth et al., 2016). Defining project management competence becomes imperative, as project managers are instrumental in project success across sectors. This offers a strategic pathway for managers to develop the skills required for optimal performance during project implementation.

The critical role of competent project managers in infrastructure development has generated substantial academic and professional interest in addressing project management competence issues (Li et al., 2020). These scholarly and industry investigations conceptualise competence broadly by categorising and identifying constituent elements. Some studies have examined competence by sector, whereas others have focused on project type (Dias et al., 2014; Ahadzie et al., 2009; Abdullah et al., 2018). Most studies consider infrastructure development lifecycles holistically. However, this approach is restrictive, as each infrastructure stage presents unique complexities that require tailored competencies. Competency mismatch during complex construction can precipitate failures (Mouchi et al., 2011).

Remington and Pollack (2016) and Kermanshachi et al. (2021) postulated that the issue of competence shortfall during project development is related to the inability to implement suitable project strategies to support project managers. They emphasised equipping managers with dynamic strategies to manage complexity. Building on this, Nyarirangwe and Babatunde (2021) propose developing tailored strategies to aid project managers in improving their performance. Accordingly, this study identifies mega-construction competence factors in Nigeria and contributes to the conceptual framework by addressing the role of digital construction in aiding project managers in managing complexity. The findings elucidate the relationship between digital construction and competence in mega-infrastructure projects.

5.2 Overview of Research Methodology

The second objective of this study was to determine the competence factors that project managers consider critical for successful large-scale infrastructure construction in Nigeria. A qualitative approach using semi-structured interviews via video teleconferencing allows for an in-depth understanding of project managers' perceptions by providing sufficient time for thoughtful responses (Creswell and Creswell, 2017). Compared to structured and unstructured interviews, the semi-structured format enables flexible, open-ended data collection for more robust, empirically grounded insights (Hammarberg et al., 2016). It also facilitates the observation of nonverbal cues to enhance transcription accuracy. Unstructured interviews increased inconsistencies, while structured interviews were considered overly rigid, limiting deeper exploration (Fellows and Liu, 2015).

An interview protocol was designed based on the literature to capture construction competence factors. Adhering to COVID-19 protocols, online interviews have enabled wider accessibility, lower costs, and reduced social desirability bias. Although in-person interviews traditionally build rapport and capture non-verbal cues better, limitations have been mitigated by carefully reviewing recordings multiple times (Saarijärvi and Bratt, 2021). Experienced infrastructure project managers were asked to identify, explain, and rate the competence factors, suggesting the most critical. They also discussed the evolving complexity of mega-constructions.

The deductive interview design incorporated the literature and researcher experience to shape an explanatory framework. Narrative accounts facilitated analysis and ensured an accurate reflection of competence perspectives. Prospective participants received email invitations and virtual links. With consent, the interviews were recorded on a mobile device and meticulously transcribed into separate files by affiliation (Kvale, 1996). This organised approach ensured accurate data reflecting the competence factor views.

Microsoft Word's voice recognition feature enabled swift, precise transcription from recordings, an improvement over manual methods that are prone to missing non-verbal cues (Vindrola-Padros and Johnson, 2020). The researcher repeatedly listened to recordings to capture nuances and familiarise themselves with the content, thus enhancing accuracy (Vindrola-Padros and Johnson, 2020). Reiterating interview question titles aids transcription quality and data categorisation (Kvale, 1996). Post-transcription, the researcher thoroughly reviewed the transcripts to correct errors, ensuring a clean, precise dataset for analysis.

Narrative analysis identified salient words, themes, and concepts in the qualitative data. Quantifying the interrelationships established relevant themes and drew meaningful inferences. Descriptive statistics analysed quantitative data, providing key findings and insights into competence in mega-construction, specifically in Nigeria. The results are presented in the following sections. A comprehensive discussion examines the implications and significance of the results.

5.3 Results

Descriptive statistics quantitatively summarised the data collected in this study. The sample comprised twenty-seven professionals, considered an adequate qualitative sample size based on prior research (Li et al., 2020). Of the participants, 15 held project manager roles, while 12 were site managers. Furthermore, the participants had extensive field experience with over ten years of industry involvement. Remarkably, 16 individuals had over two decades of mega-infrastructure experience across distinct project types. This experience adds value and credibility to the insights gathered. This research aims to provide a comprehensive and reliable understanding of the investigated topic by utilising descriptive statistics and ensuring a diverse, seasoned sample. The data collected from professionals with extensive industry knowledge will contribute to the robustness and validity of the findings, allowing for meaningful insights into the competence factors relevant to project managers in mega construction projects.

Table 5.1 Participants' Professional Experience and Project Type Executed

S/No	Participant	Professional affiliation	Years of experience	Project type involved
1	PM1	Project Manager	Over 20 years	Maritime university construction
2	PM2	Project Manager	Over 15 years	Road construction
3	PM3	Civil Engineer	Over 20 years	Rail construction
4	PM4	Civil Engineer	Over 20 years	Rail construction
5	PM5	Project Manager	Over 20 years	Hydropower plant
6	PM6	Project Manager	Over 20 years	Rail construction
7	PM7	Architect	Over 10 years	Health facility
8	PM8	Civil Engineer	Over 20 years	5Km bridge construction
9	PM9	Civil Engineer	Over 20 years	Piling construction
10	PM10	Civil Engineer	Over 20 years	Monorail construction
11	PM11	Quantity Surveyor	Over 10 years	Airport construction
12	PM12	Civil Engineer	Over 20 years	Road construction
13	PM13	Project Manager	Over 15 years	Mass housing development
14	PM14	Project Manager	Over 15 years	Commercial district construction
15	PM15	Project Manager	Over 15 years	Dam construction
16	SM1	Civil Engineer	Over 10 years	Maritime university construction
17	SM2	Civil Engineer	Over 15 years	Hydropower plant
18	SM3	Civil Engineer	Over 20 years	Rail construction
19	SM4	Civil Engineer	Over 20 years	Health facility
20	SM5	Civil Engineer	Over 20 years	5Km bridge construction
21	SM6	Builder	Over 20 years	Piling construction
22	SM7	Civil Engineer	Over 29 years	Monorail construction
23	SM8	Builder	Over 10 years	Mass housing development
24	SM9	Project Manager	Over 15 years	Airport construction
25	SM10	Civil Engineer	Over 20 years	Airport construction
26	SM11	Builder	Over 15 years	Health facility
27	SM12	Civil Engineer	Over 20 years	Commercial district construction

Q.1 Which competence do you find more critical during infrastructure construction?

Pleasantry was exchanged at the commencement of the interview to establish a comfortable atmosphere. Due to the distinct terminologies used in construction theory and practice, it is essential to familiarise participants with critical terms (Koskela et al., 2002). Participants were asked to identify the competence they found to be significant in managing infrastructure construction. Notably, the term 'effective communication' was mentioned 18 times in response to this question. Participants unanimously agreed that without effective communication at the construction site, the project was prone to significant rework, delays, and cost overruns, resulting in demotivated workers and dissatisfied clients.

Participant PM14 emphasised the importance of promptly addressing communication gaps during construction. The PM14 *suggested that if communication issues become frequent, it is practical to halt work on-site and identify the root cause to prevent further harm to the project's overall objective.* This highlights the significance of effective problem-solving skills, as core competence project managers need to develop to manage construction complexity. Participant PM1 was delicate regarding this issue. *S/he emphasised the importance of effective on-site communication in creating a collaborative work environment where everyone understands their responsibilities, receives timely information, maintains project momentum, and ensures timely completion within the allocated budget*. SM4 shares a similar perspective, stating that *communication serves as a conduit for a timely and accurate information exchange. Regular updates, progress reports, and feedback sessions allow for better decision-making, enabling us to address issues promptly. This proactive approach prevents delays, minimises disruptions, and fosters a culture of accountability and transparency*. Mega construction involves translating the umpteenth piece of information into technical drawings to achieve the final product. In mega construction projects, effective communication is imperative because complex technical drawings must be interpreted to achieve the desired final product (Senaratne and Ruwanpura, 2016).

In addition, the discussion touched upon the significance of planning. Participants PM9, PM13, SM2, and SM9 emphasised the vital role of planning in construction success. They highlighted the need to envision the project from start to finish and emphasised the importance of scheduling and allocating resources to align with work packages, ensuring a well-organised on-site operation. This viewpoint reinforces Crawford's (2005) assertion that planning competence is a critical success factor in large construction projects. Participant SM2 shared their experience managing numerous subcontractors, highlighting the chaos that can arise without effective planning: "*I supervise over a hundred subcontractors supporting construction work on-site, and each party is in a hurry to round up their work package and move to the next project, leading to a disorganised and chaotic work site. Without effective planning, I would be left dumbfounded and overwhelmed on-site on managing the copious resources consumed daily."*

Furthermore, in mega-construction projects with inherent complexities, diligent planning and resource scheduling are essential for anticipating potential challenges and mitigating risks (Nguyen et al., 2015). This encompasses effectively allocating human resources, equipment, materials, and budget considerations. During Mass Housing construction, PM13 stated that *effective planning allows project managers to set clear objectives and define the scope of work. By establishing specific goals and outlining the project's boundaries, we provide a roadmap for the entire team. This clarity ensures that everyone understands the project's direction and contributes to a common purpose*.

Despite extensive planning, PM4 reiterated that, *as professionals, we need to acknowledge that challenges can arise unexpectedly despite meticulous planning*. In such situations, project managers must swiftly analyse the circumstances and make informed decisions to manage these challenges effectively. Taking prompt and well-considered actions can prevent a project from deviating from its objectives. This may involve adjusting resource allocation, revising timelines, or implementing contingency measures to keep the project on track. Therefore, decision-making competence is a critical requirement for successfully navigating construction projects.

Belay et al. (2017) emphasised decision-making as an essential competence for managers to navigate project-related challenges during construction. Participant PM11 expressed that *the time spent deliberating on the right decision on-site could result in a 10% increase in the project duration and budget every other day. Moreover, making an incorrect decision could lead to catastrophic project failure*. A competent project manager's ability to adapt to and make sound decisions while considering long-term implications is a vital attribute. In this regard, PM5 highlighted the importance of assessing the potential consequences of decisions in the present and future, taking a holistic view of the project requirements for long-term success. This underscores the need for project managers to prioritise available resources logically to ensure optimal performance during construction (Kerzner, 2017). Moreover, this is also a plausible reason why it is pivotal to identify mediums that would support managers in making coherent decisions on-site.

The narrative also captured the significance of coordination during mega-construction projects. Project managers unanimously agree that coordination plays a paramount role in their success. Given the magnitude and complexity of these endeavours, seamless collaboration among stakeholders, such as architects, engineers, contractors, and subcontractors, is vital. Effective coordination ensures alignment, synchronises activities, manages resources efficiently, and minimises delays or conflicts. Mega construction projects involve numerous interdependent tasks and intricate timelines, making coordination essential for maintaining project schedules, adhering to quality standards, and delivering within the budget.

Effective coordination is paramount for projects with an extensive site area and perimeter, like airport facilities. PM11 and SM10 highlight the importance of effective coordination in fostering better collaboration among project participants. They advocated that *project managers create an environment in which everyone works towards a shared goal by promoting open communication channels and encouraging teamwork. This collaborative approach enhances synergy and enables timely resolution of issues.*

According to SM3, project progress can be hindered during rail construction *without coordination, leading to cost overruns, rework, and potential safety risks. Therefore, I cannot stress enough how crucial it is to prioritise and excel in coordination during mega-construction projects.* PM4 also shared a similar belief, emphasising how effective coordination enhances construction performance by harmonising and aligning the efforts of multiple stakeholders for smooth and efficient project execution. Coordination is particularly crucial in rail and road construction projects because of their extensive scope and the need to maintain synergy throughout the project to avoid deviations from objectives.

Other critical terms mentioned by participants included team building (8), problem-solving (8), information management (8), and negotiation (7), as depicted in the graph below (Figure 5.2), which illustrates the frequency of each factor derived from the interview transcript. As projects become increasingly complex and intricate, managers must continuously develop their competence to ensure optimal performance during mega-construction.

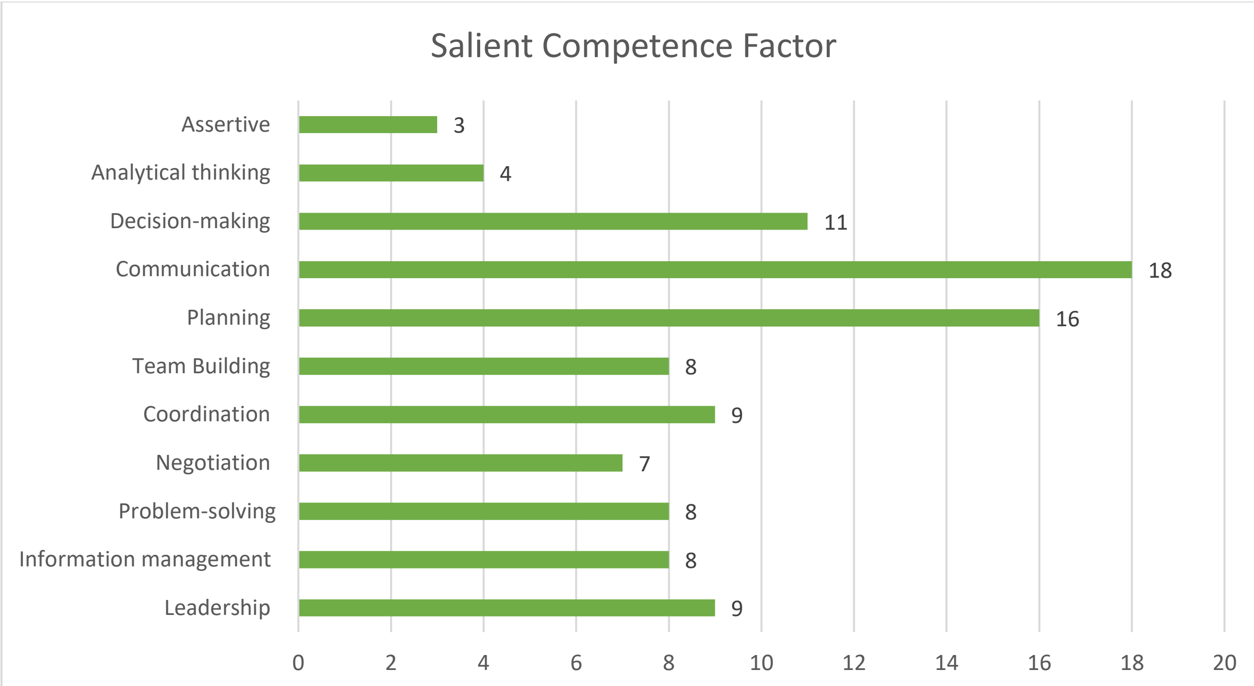

Figure 5.1 Vital Competence Factors

Q.2 Please rate the importance levels of these factors on the extensive project management competence list.

During the interview, participants were prompted to rank the importance they attributed to each competence identified from the literature on a scale of 0 (insignificant) to 10 (highly significant). The graphical representation of their responses, as displayed in Figure 5.4, provides insights into the perceived significance of specific competencies in managing complexity during mega-construction projects. The x-axis represents the number of participants who responded to each rating level. Various colours were assigned to distinguish the rating levels: pine green corresponds to level 5, yellow represents level 7, peer green signifies level 8, orange denotes level 9, and Munsell yellow is used for level 10. These colour differentiations aid in visually interpreting the data with other colours in the graph.

Interpretive analysis of the graph revealed intriguing dynamics. It is evident that three of the 27 participants assigned problem-solving a Level 5 influence within the construction context. A similar number of participants attributed a Level 7 influence on problem-solving in mega construction. Another three respondents assigned problem-solving a level 9 influence, whereas the majority—63% or 17 out of 27 participants—conferred a paramount, level 10 influence on problem-solving for project managers dealing with complexity during mega construction. Further examination revealed that 17 participants perceived coordination and team development as competences with a crucial level 10 influence on project managers during mega construction. Additionally, 67% (18 participants) acknowledged that communication, decision-making, and leadership are critical competencies that strategically influence mega-construction projects.

Consequently, it can be inferred from Figure 5.4 that a significant majority of the participants, over 50%, strongly agree that planning, communication, leadership, team development, problem-solving, teamwork, and decision-making are key competence required by project managers to anticipate positive outcomes when managing mega infrastructure projects. These findings resonate with the work of Edum-Fotwe and McCaffer (2000), who also identified leadership, communication, and problem-solving as foundational skills necessary for managers to augment their overall competence. This alignment underlines the relevance of the results of the current study and highlights the necessity for managers to cultivate these skills for effective complexity management during infrastructure construction.

Similarly, Lei and Skitmore (2004) argued that communication, decision-making, and planning are crucial skills project managers should develop to navigate the prevailing challenges in the 21st-century construction industry. Subsequent studies by Li et al. (2020) and Bashir et al. (2021) expanded on this premise, identifying foundational knowledge and skills, goal orientation, uncertainty and change management, stakeholder management, coordination, resource planning, negotiation, and scope definition as the key competencies required for thriving in international projects, particularly in emerging and developing countries.

Interestingly, aptitude, confidence, administration, and directing competence were not deemed essential in determining the construction performance in large infrastructure projects. This observation was inferred from the participants' demeanour, implying that these competencies lack a technical orientation. Further substantiating this, Figure 5.4 indicates that less than 19% of the participants rated these factors highly during mega construction. Participant SM5 opined that characteristics such as confidence and uprightness should not be viewed as managerial competence since the primary focus of any project manager should revolve around achieving the project goal. SM5 further emphasised: *When managing a project, all managers think of last before bed, and the first thing when awake entails how to achieve the project goal*". PM5 expressed that ethical management is desirable in construction but does not necessarily translate into successful complexity management.

Participant SM1 suggested that administrative skills should not be the sole focus of the project manager, given that mega-construction projects typically have numerous administrative personnel to handle such tasks. Instead, managers should focus on enhancing construction site culture. Similarly, PM5 suggested that *while negotiation skills are undoubtedly valuable in various aspects of project management, I believe that they may not be the primary factor in improving construction performance on site*. Although valuable, negotiation skills may not be the primary determinant in improving construction performance. Effective communication, proactive coordination, and strategic planning play more significant roles, especially at the commencement of the project. PM4, PM7, SM11, and SM3 collectively recommended that project managers prioritise effective communication, proactive problem-solving, and strategic planning to achieve superior outcomes during mega construction. Their opinion suggests that cultivating strong relationships, anticipating challenges, and maintaining control over project parameters can create an environment conducive to success.

Overall, the insights gained from these findings and previous research consistently highlight the significance of communication, decision-making, planning, leadership, team development, and problem-solving as essential competencies for project managers. These competences are crucial for effectively managing complexity and achieving positive outcomes in construction projects. The findings reinforce the importance of developing and enhancing these competencies to enhance overall construction performance.

Q.3 Rank the seven competence elements you find most important during infrastructure construction

The interviewer asked the participants to rank seven construction-related critical competence factors from a predetermined list. Notably, 30% of the participants deemed communication the paramount competence to support on-site project managers. As previously cited, project managers professed that the "*absence of effective communication on a construction site invariably results in significant rework, and workers tend to lose motivation*." This insight underscores the significant role of effective communication in augmenting the performance of mega-construction projects.

Equally significant, an identical proportion of participants (30 %) regarded planning as a preeminent competence, upon which managers should depend on executing their roles during infrastructure construction. Leadership was viewed as the most significant factor in the context of infrastructure construction by 19% of the respondents. However, this study does not emphasise leadership because of its nontechnical orientation. Seven participants attributed substantial importance to decision-making, coordination, and problem-solving, while one respondent awarded teamwork and information management high rankings. Table 5.2 highlights the top seven competence factors derived from the given options and records the frequency of their occurrence for each rank placement.

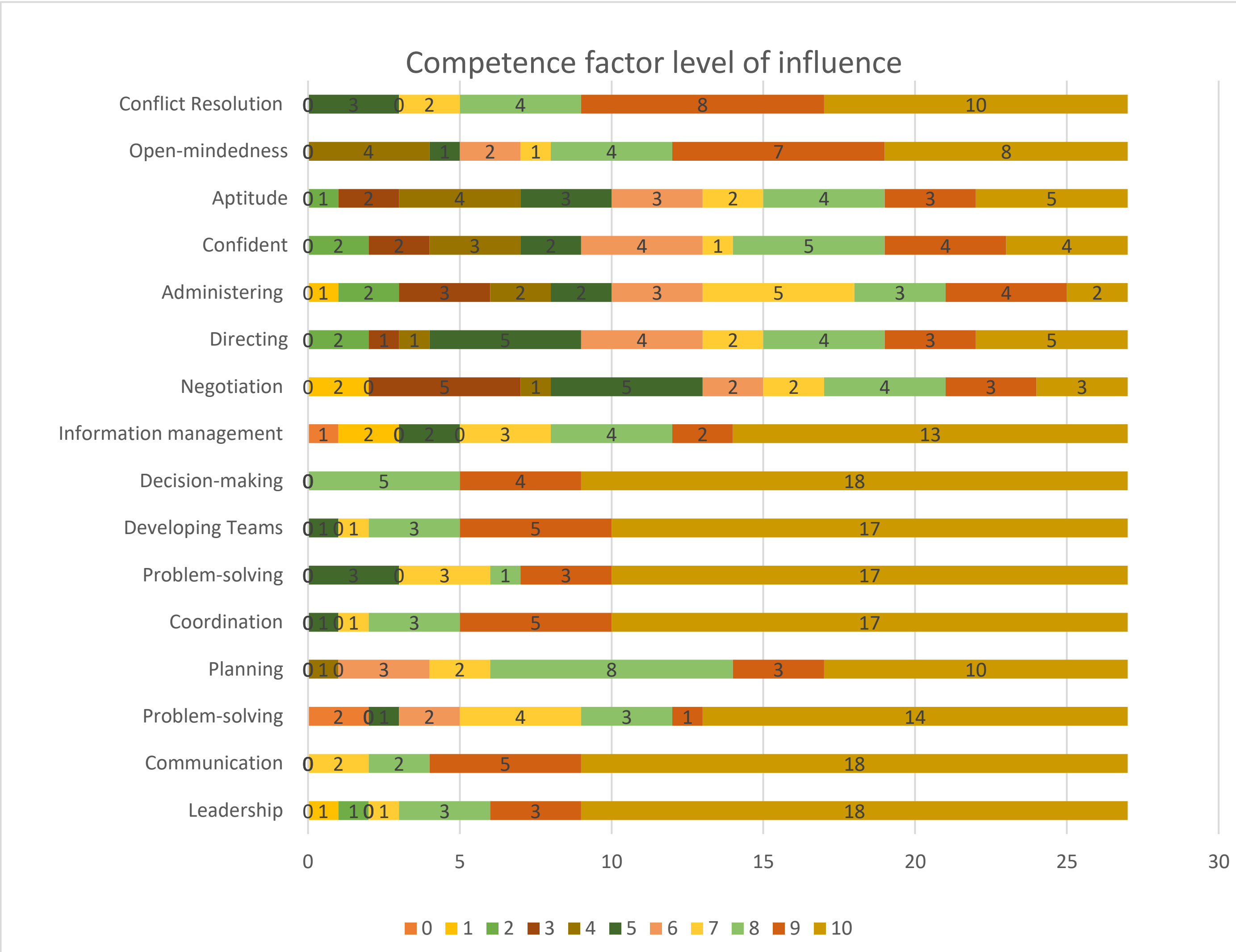

Figure 5.2 Competence Factor Significance during Construction

As illustrated in Table 5.3, a notable proportion of respondents—30%—ranked communication and planning as the most critical competence for project managers to navigate the challenges of mega construction projects in Nigeria. Participants also conferred substantial importance to decision-making and leadership, with 41% placing this competence in the second and third positions. Coordination was ranked fourth by 44% of participants, while problem-solving, information management, and team development followed suit and ranked in a respective sequence. This study focuses on these competencies as integral components that supplement the proposed conceptual framework presented in Chapter 7.

Table 5.2 Top Seven Ranked Competence in Frequency Order

Ranking	Competence Factor	Frequency
1	Communication	30%
1	Planning	30%
2	Decision-making	41%
3	Leadership	41%
4	Coordination	44%
5	Problem-solving	48%
6	Information Management	50%
7	Developing teams	52%

Q.4 Have infrastructure projects gotten more complex over the years

In the final phase of the interview process, interviewees were prompted to reflect on whether infrastructure development had grown in complexity in recent years. An overwhelming majority (20 out of the total participants) responded affirmatively, attributing mounting complexity to several factors. Primarily, they mentioned that clients' competitive drive bent on outpacing their competition by constructing more monumental edifices. Furthermore, they attributed the surge in complexity to advancements in technology within the construction industry, escalating project sizes necessary to cater to growing populations, and intensifying the pressure to adhere to the rigid standards of the iron triangle in project completion. One participant, designated as PM3, pointed to technological innovation as a leading factor, stating, "*The advancements in construction technologies, though beneficial, have inadvertently led to an increase in the complexity of the construction process, primarily due to the steep learning curve required to utilise these tools effectively*." This sentiment was corroborated by findings from a previous study conducted by Söderlund et al. (2017).

Several other participants, specifically PM4, PM7, and SM3, cast blame on clients' increasing expectations. PM7 elaborated that *it is funny how times change, is not it? These days, people care about the environment, and it is trickling into everything, including construction. Folks now ask for everything to be green and eco-friendly. Therefore, what does that mean to us in construction? It is not just about bricks and mortar. We have come to think about using techniques that are kind to the planet, systems that save energy, and materials that do not cost the earth. However, it is not always a walk in the park, right? When making decisions, juggling all these demands while still trying to meet the project's goals is another level of complexity. However, that is now the world in* *which we live.* Söderlund et al. (2017) echoed a similar sentiment, highlighting how clients' demand, push for standardisation, and stiffer regulations have increased the complexity of megaprojects over the years.

However, four participants countered this consensus, arguing that the perceived increase in complexity reflects the industry's evolution. SM9 argued that given project managers' continuous professional growth and development, the increase in project complexity should not be a cause for concern. As Ekrot et al. (2016) pointed out, this assertion is disputable: the project success rate determines the imbued antecedent project managers learn. Given the often-low success rates associated with infrastructure construction projects, it is questionable whether project managers can learn positive lessons from these experiences. The uniqueness of each project and disparity further hinder the ability to learn from past experiences. Hence, it is crucial to identify mediums to support managers in developing their competence in managing construction projects in developing countries.

PM2 offers a unique perspective, viewing the complexity inherent in modern mega-construction projects as an opportunity rather than a deterrent. PM2, as quoted: *Certainly, construction projects have become more complex in several ways, but I do not see this as a cause for concern. Instead, I view it as an exciting challenge that motivates us to grow and innovate. With technological advancements, changing regulations, and larger-scale projects, we constantly adapt and find innovative solutions.* This aligns with Stephen Hawking's characterisation of the 21st century as the "***century of complexity***" and the Project Management Institute's assertion that complexity will continue to increase and practitioners must adapt (Bakhshi et al., 2016); hence, finding innovative strategies is a viable option.

In conclusion, while the perspectives on escalating complexity in construction projects vary, the consensus suggests a comprehensive approach that embraces complexity as a part of progress and seeks to equip project managers with the skills and competence necessary to manage it effectively.

5.4 Discussions

Study β's survey of experienced project managers provides valuable insights into Nigerian infrastructure competence requirements. However, the relatively small sample size and lack of segmentation by project type limits the generalisability of the findings (Sharma, 2017). Nevertheless, the results critically highlight communication, decision-making, and planning as the most imperative competencies, underscoring the substantial complexity intensity inherent in mega-construction projects that demand sophisticated coordination, allocation, and leadership (Crawford, 2005). However, the participants' subjective self-assessments warrant caution when interpreting the precise relative importance of each competence factor.

In particular, prioritising planning competence strongly highlights its indispensable role in mega-construction, given the multifaceted human, material, financial, and technical resources that must be intricately coordinated (Qazi et al., 2016). Project managers face immense challenges in developing comprehensive schedules, optimally designing work packages, forecasting needs, and allocating resources to seamlessly orchestrate complex construction tasks. However, a lack of benchmarks makes it difficult to gauge the adequacy of current planning capabilities critically.

Furthermore, participants unsurprisingly ranked team development low, likely because the industry relies on specialist subcontractors. This reveals a concern about over-dependence that compromises opportunities to cultivate in-house capabilities and institutional learning. Enhancing team-based competencies could improve integration and outcomes in complex projects (Lei and Skitmore, 2004). Effective communication is also of immense importance during large-scale construction. Comprehensive communication planning is indispensable, given the numerous professionals involved. Without this, avoidable errors can occur, increasing the project budget and duration and compromising quality. Project managers must communicate schedule and specification changes effectively to ensure timely instructions for positive outcomes (Gamil et al., 2019).

Leadership trait was also emphasised as an essential competence. Given the extended durations, large workforces, and on-site unpredictability, project managers must demonstrate technical and emotional intelligence to successfully navigate uncertainties. These competencies align with the foundational pillars highlighted by Edum-Fotwe and McCaffer (2000), who identified leadership, communication, and problem-solving as crucial for competence development. This further validates the study’s findings, emphasising the necessity for Nigerian project managers to cultivate these competencies to enhance regional infrastructure delivery.

The findings regarding the relative importance of each competence factor during construction revealed that planning, communication, leadership, team development, problem-solving, teamwork, and decision-making are crucial for navigating complex infrastructure projects. These findings align with Lei and Skitmore's (2004) assertion that competent managers must possess strong communication, leadership, proactive decision-making, and focus on thriving objectives. Chen et al. (2008) further reinforced these findings, underscoring communication, planning, negotiation, resource management, and teamwork as essential construction management competence components.

The participants consistently perceived competence development as necessary during infrastructure projects, as shown in Table 5.2. Managers ranked communication and planning as most critical during construction. However, team development ranked lower, possibly because of reliance on specialist subcontractors as opposed to in-house workforce development. Awareness of goals and scope change recordkeeping also ranked lower, potentially attributable to participants' strong project lifecycle goal awareness, as expressed by SM5. Furthermore, managers have acknowledged Nigeria's increasing infrastructure construction complexity as a global trend. As the Project Management Institute advised, complexity will continue to increase, making it imperative to devise mitigation strategies. This study proposes and explores the potential of digital construction to bolster project managers' competence in handling Nigerian mega-construction complexity.

5.5 Conclusion

The central focus of Study β was to explore project manager competence based on geographic location and project type uniqueness. A semi-structured interview methodology gathered insights into the competencies that Nigerian project managers consider vital during infrastructure construction. This approach aims to foster competent managers who can oversee such projects. The competence areas emphasised effective communication, resource planning, complex problem-solving, and sound decision-making. Conversely, traits such as open-mindedness, aptitude, and confidence were less relevant to infrastructure-construction roles. The study suggests that managers continually refine these competencies through tailored, ongoing training and professional development.

The key findings highlight essential competence for developing competent infrastructure project managers in Nigeria. They also inform professionals of potential competence gaps, prompting a more cautious approach to commitments. The top seven identified competencies outlined in Table

5.2 define the proposed relationships within the conceptual framework. However, leadership skills were excluded because they focus on technical competence, deemed more crucial during construction. Furthermore, this study provides a foundation for additional research on project manager competence in developing countries.

Persistent delays, cost overruns, and defects underscore the urgency for change and have become normalised deviations regionally. Prior studies suggest that highlighting the most significant competence factors by project type and location could enable project managers to refine their competence further. These findings are evident in Nigeria's knowledge of project managers' competence development. However, the conclusions are constrained to infrastructure construction in Nigeria. Further research on competence development across project types, phases, and geographic settings is required.

Summary

This chapter identified project management competence factors critical for managing complexity in Nigerian mega-construction projects. Despite the existing literature underscoring competence identification across industry, geography, and project stages, this perspective is distinctly lacking for large-scale construction in Nigeria. A semi-structured interview gathered nuanced insights from experienced project managers. Narrative analysis of the qualitative data revealed perceptions of essential competencies for successful mega-construction-communication skills, planning, problem-solving, and decision-making. The findings align with Nyarirangwe and Babatunde (2021) regarding the necessity of pivotal competence factors to comprehensively evaluate project strategy efficacy. The elucidated competence, answering the second objective, will be used to assess the effectiveness of digital construction during mega-construction in Nigeria. Given the prevalent studies on Nigeria's construction digitalisation, the next chapter investigates this strategy's applicability to mega-construction sites, bridging knowledge gaps for large-scale project management.

Chapter 6 Study γ – Observational Insights of Digital Construction

This chapter presents findings from an exploratory case study assessing the influence of digital construction on project manager competence in infrastructure projects. Digital construction involves the integration of various digital technologies into construction operations to enhance performance. The study adopted an observational methodology across nine mega-construction project sites in Nigeria that exhibited digital tool usage. The data were compiled into themes illuminating competence areas: communication, planning, coordination, supervision, and monitoring. The chapter documents how tools such as BIM, drones, mobile devices, and collaborative software assist managers in handling multifaceted on-site complexities. Examples demonstrate the flexibility of digital construction in augmenting human capabilities beyond the limitations of prevalent industry strategies. This chapter also provides practical insights and signals that construction firms should incorporate digital construction into their project environments.

Objective Three: *Investigate the influence of digital construction on project managers' competence in comprehending and navigating complex realities during infrastructure construction*

6.1 Research Purpose

The underperformance of mega-infrastructure projects in terms of cost and timely completion, particularly in developing countries, has primarily been attributed to project managers struggling with construction complexity. As elucidated by Remington and Pollack (2016), the root of this issue often lies in the inadequacy of traditional project management strategies to enhance managerial competencies to handle the inherent intricacies of megaprojects. Consequently, when complexities emerge, compounded by inherent uncertainties and difficulties, project managers frequently find themselves ill-equipped with minimal recourse to manage such challenges effectively (Kermanshachi et al., 2021).

The International Project Management Association [IPMA] (2015) proposed self-development, peer development, education, training, coaching, mentoring, simulation, and gaming as potential strategies for individual managers to develop competence. However, given the unique characteristics of each project type, this study questions the practical viability of these suggestions (Shenhar and Dvir, 2008). These guidelines are designed for specific project categories. Hence, this study proposes adopting a digital strategy implemented in manufacturing as a potential solution for developing project management competence to handle complexity-induced challenges during infrastructure construction.

A digital strategy involves integrating various digital technology tools to enhance construction operations and optimise industry performance. Section 2.6 discussed this proactive approach, presenting previous studies demonstrating digital tool combinations on large construction sites. However, this research employs a case study method to ensure that theoretical findings genuinely reflect Nigerian construction site realities. This method enables theory to mirror practice (Yin, 2012) accurately. Through direct observation, tool usage was assessed onsite to understand the influence of digital construction on project management competence. This provides valuable theoretical and practical insights into the progress of digital construction at mega-construction sites. This also supported the focus group when designing the survey instrument for the main study. The scope was limited to the prevalent competence factors in Chapter 5 during Nigerian mega-construction. The following sections comprehensively address the third objective of this research.

6.2 Case Study on Mega Construction Sites

This study adopted an exploratory case study approach involving direct observation of project managers' roles within construction scenarios to depict interactions with digital tools in the field (Yin, 2012). This unobtrusive data collection method reduces potential bias, which is significant considering that project managers may offer contradictory narratives due to potential afflictions or biases towards site tools.

To comprehensively understand how managers engage with digital tools in real-world settings, observations have focused on how these tools are deployed for daily operations, particularly regarding their role in managing construction process complexity. The sites were carefully chosen based on incorporating at least two digital tools. Official observation requests were dispatched to various construction sites registered with the Federation of Construction Industry (FOCI). Nine sites were selected, considering accessibility and meeting the mega-infrastructure project criteria outlined in Table 6.1.

Direct observational data were compiled into a comprehensive report for the initial study phase in the following section. Findings were organised into thematic categories illuminating key complexity-induced challenges requiring competent project manager skills: Communication, Planning and Coordination, and Supervision and Monitoring.

Although these categories provide a helpful framework for understanding competence areas enhanced by digital tools, it is essential to acknowledge the broader beneficial impacts of these technologies. Additional challenges were noted but were beyond the scope of this study. However, Chapter 7 empirically explores the transformative influence of digital construction on the roles of construction project managers. This offers opportunities for future research to expand on the identified categories and explore the broader potential of digital tools in augmenting managerial competence for managing complexity in construction projects.

Table 6.1 Observed Project Sites (Source: Own study)

Project Site	Project Description
A	A maritime university development estimated at $1.5 billion.
B	200km Road with auxiliary bridge construction costing $750 million.
C	Erosion Control Project under the UN ecological fund initiative.
D	156km rail line valued at $1.5 billion
E	2733km standard gauge rail line construction at $11.1 billion.
F	284km single-track rail line valued at $1.96 billion.
G	Hydropower plant construction with a contract sum of $5.5 billion.
H	1.7km Bridge valued at $ 1.2 billion.
I	550-meter-long Gravity Dam construction

6.2.1 Communication

Research has found that walkie-talkies and Building Information Modelling (BIM) have become ubiquitous in executing mega-construction projects. These tools enhance communication and visualisation, allowing project managers to handle the inherent complexity involving many participants, dispersed teams, and project-type specificities.

For instance, Project A integrated BIM with a collaborative tablet to streamline on-site communication between the participants. This enabled supervisors to contact the project manager to clarify details and report issues, addressing challenges from the immense scale of construction, abundant information, numerous specialists, and scattered teams. These digital tools positively impacted the project manager's competence, enabling the effective real-time coordination of schedules and details.

A specific example shows the effectiveness of digital construction when installing a lift shaft 2 km away from the project office. Traditional practices require the manager's physical presence on-site, wasting significant time and effort. However, using the project tablet, the specialist contractor could send a video of the problem area, facilitating a digital discussion between the foreman, project manager, subcontractor, and structural consultant. This efficient communication enables a swift issue resolution pertaining to the lift shaft.

In Project H, sociocultural stakeholders and community tensions severely disrupted work progress. The project used CCTV and augmented reality (AR) integrated into a mobile application to address this. The application contrasted the 3D model with real-time work progress. This innovative approach allows managers to manage political tensions effectively, providing a more immediate and far-reaching communication solution than traditional press conferences (Lundell, 2010). The adoption of digital tools such as LIDAR, GIS, and UAVs supports a more responsive information management strategy (Kapogiannis, 2019). These tools and mobile and cloud computing foster an integrated project environment that helps managers cope with work complexity more competently.

Harmonising digital tools into a digital construction strategy significantly enhances project managers' competence in communication, information management, planning, programme management, and problem-solving. Tool integration enables incisive decision-making, information management, and on-site coordination, thus effectively tackling complexities. These tools can help managers mitigate complexity-associated challenges and improve productivity and performance.

6.2.2 Planning and Coordination

Mega infrastructure projects require substantial resources and multidisciplinary inputs. Thus, project managers must schedule activities and allocate resources, such as budgets, materials, and personnel, across interdependent tasks to achieve objectives (Andy and Price, 2010). For instance, Project B's observations revealed that a road construction project commenced work from three strategic locations to ensure prompt completion. The project manager contended with complexity sources, including project scope, material and labour scheduling, coordinating dispersed teams across locations, and deploying machinery and workers. This necessitates effective coordination, which is critical for infrastructure construction, productivity, and performance (Ochieng and Hughes, 2013).

To assist the manager, the main contractor provided various digital tools, including Unmanned Aerial Vehicles (UAVs), n-dimensional Building Information Modelling (BIM), cloud-based routing software, mobile devices, Geographic Information Systems (GIS), and Radio Frequency Identification (RFID). This enabled the effective coordination and delegation of machinery across the 200 km road project. The manager tackled complexity by visualising and simulating equipment usage on a 3D BIM-enabled GIS model, thereby enhancing planning and decision-making capabilities. The agreed equipment schedule was uploaded to a cloud-based routing software, enabling participants to track the expected timing and locations. RFID tags monitored through GPS ensure schedule compliance.

Moreover, integrating these digital tools reduces on-site inefficiencies, as research has indicated that equipment location, scheduling, and delegation significantly contribute to task complexity in large engineering projects (Nasir et al., 2010). Leveraging these tools can effectively manage task complexity. Due to the vast survey area of Project C, the manager utilised UAVs and remote sensing to identify eroded areas, track progress, and plan activities aligned with the project baseline. This approach enables comprehensive planning and coordination across large projects without physical site inspections.

Similarly, Project E and F managers adopted integrated collaborative software via mobile computing to coordinate with supervisors and communicate real-time schedule changes. Given the demonstrated benefits, integrating digital tools into workflows is becoming increasingly pertinent for project managers. This can enhance planning, project management, information management, and problem-solving capabilities, ensuring successful mega-infrastructure delivery. Digital construction could offer a comprehensive solution to complexity-related construction challenges and improve the overall project delivery.

6.2.3 Supervision and Monitoring

While the discussion thus far raises crucial points about the benefits of digital construction, particularly concerning project management, a more comprehensive analytical approach is necessary to evaluate the impact and potential of digital construction. The first point to consider is the role of the project manager. Overseeing numerous interconnected daily activities, these professionals often face overwhelming workload. Research by McCullouch (1997) indicated that project managers spend about half their productive time collecting and analysing on-site data, which is even more complex and cumbersome for large-scale infrastructure. Traditional monitoring systems are often inadequate, with frequently outdated data before corrective alignment with performance baselines can occur.

Attempts to address these issues have traditionally focused on structured training (Dias et al., 2014) and technological tools (Panas et al., 2014) to improve project management competence. However, the applicability of training for infrastructure construction has been criticised because of the unpredictable nature of such projects, in contrast to the traditional project management training principles.

Considering these insights, this study argues that project managers can better handle various project complexities by adopting digital construction methods. For example, the observed projects used various digital tools for supervision and monitoring during construction. Drones and LIDAR were employed in Project G. The manager used drones for supervision because the site's size, topography, and team dispersal introduced complexities that impeded effectiveness. However, these tools support the efficient functioning of managers. Drones surveyed the site hourly, whereas LIDAR estimated the work completed every other day.

Managers in Projects B, D, E, and F primarily relied on drones, GIS, and LIDAR to oversee and monitor construction output. Combining these tools enables seamless project surveying and baseline alignment. Notably, younger managers across Projects B, C, D, E, and G seemed more inclined to leverage digital tools than older baby boomer managers. This likely stems from generational differences in technological familiarity, with younger managers coming of age during the technological revolution.

6.3 Conclusion

This research presents a new perspective on enhancing project managers' competence in construction, advocating for a proactive, evolving approach that integrates digital tools into an information-driven strategy. The study demonstrates that digital technology can augment human capabilities and understanding, thereby facilitating the effective execution of complex construction site tasks. This competence enhancement through digital tools transcends the limitations of specific project environments. Contrasted with other prevalent construction industry strategies, such as lean construction and concurrent engineering, digital construction offers greater flexibility to serve various construction functions and effectively address the inadequacies of these strategies.

The findings of this research offer valuable insights to construction companies seeking to optimise the digital tools used during construction. Integrating these tools yields significant combined capability benefits. Furthermore, academic institutions offering construction project management programs are encouraged to consider these findings and incorporate digital construction modules to equip future professionals with the necessary contemporary construction environment skills. The study also highlights the increasing prevalence of digital construction practices among project managers in the coming decade, further reinforced by the introduction and subsequent gains from implementing the Building Information Modelling (BIM) ISO 19650 standards.

This study has several limitations. Although observational techniques were utilised to gather data, it must be emphasised that this method is insufficient in elucidating the interrelationships between observed behaviour, motive, and underlying factors. Considering this, Section 7.3.1 empirically verifies the positive impact of digital construction on project management competence, although not all competence factors have been fully explored. Furthermore, technological capability disparities across different project sites pose challenges in accurately assessing the direct influence of digital construction on the projects under examination.

Given the rapidly digitalising nature of the Architecture, Engineering, and Construction industry, it is imperative to address the practice-research gap and identify the most effective combinations of digital tools for specific competence across project types. The significance of competence in successful construction project management underscores the need for future studies to establish an empirical digital construction-competence link, particularly in managing complexity in mega-infrastructure construction projects.

Summary

This chapter presented an exploratory case study that examines the impact of digital construction on the competence of mega-infrastructure project managers in Nigeria. The study used an observational methodology across nine construction sites with digital tools. The findings were categorised into competence areas illuminated by the tools, including communication, planning and coordination, and supervision and monitoring. The study demonstrates how technologies, such as Building Information Modelling (BIM), drones, and collaborative software, can assist managers in addressing the complexities of on-site projects. However, the observational technique has limitations in terms of eliciting the underlying relationships. The next chapter will present an empirical evaluation of competence enhancement, while this study focuses on the observed competencies and tools. The following chapter will present a construction complexity management framework and empirical evidence demonstrating the effectiveness of digital construction in enhancing project managers' competence in handling complexity in Nigerian mega-construction projects.

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Chapter 7 Framework Development and Data Analysis Presentation

This chapter builds upon prior literature review findings and previous chapters to provide a comprehensive, synthesised analysis that focuses on examining the impact of digital construction on project managers' competence in managing complexity during mega-infrastructure construction. Aligned with the study's central research theme, the hypotheses and corresponding sub-hypotheses were presented as the foundation of the conceptual framework. Rigorous inferential statistical analyses were conducted to evaluate these hypotheses using one-sample t-tests to assess project manager agreement levels. Additionally, Pearson's correlation coefficient and the coefficient of determination were used to examine the relationship between the central hypothesis and the sub-hypotheses to determine the significance of digital construction in enhancing competence in complexity management. The chapter concludes by presenting the results of the statistical analysis. These quantitative findings will serve as a basis for drawing meaningful inferences and supporting the subsequent discussion chapter, which is focused on the research objectives of assessing the role of digital construction in project manager competence augmentation for effective mega-construction complexity management.

7.1 Research Purpose

The previous chapters have comprehensively covered various aspects of the study and identified construct variables. These constructs establish a foundation for exploring digital construction as an alternative strategy for augmenting project management competence in complexity management. Effective complexity management is crucial for successful infrastructure project delivery within the iron triangle constraints. This study proposes that digital construction can solve the current Nigerian infrastructure challenges.

Based on the findings thus far, hypotheses are formulated, reinforcing the notion that project managers agree that digital construction enhances competence in managing challenges induced by mega infrastructure construction complexity. Hypotheses are derived from a thorough literature review and are supported by previous chapter findings underpinning conceptual framework development (Figure 7.1). The following section presents and discusses these hypotheses and the corresponding sub-hypotheses, providing clear research questions and an understanding of the relationship examination. By examining these hypotheses and sub-hypotheses, we aim to gain insight into the impact of digital construction on enhancing project manager competence in managing construction complexity. The subsequent discussion sheds light on the conceptual framework and hypothesis significance to the research objectives.

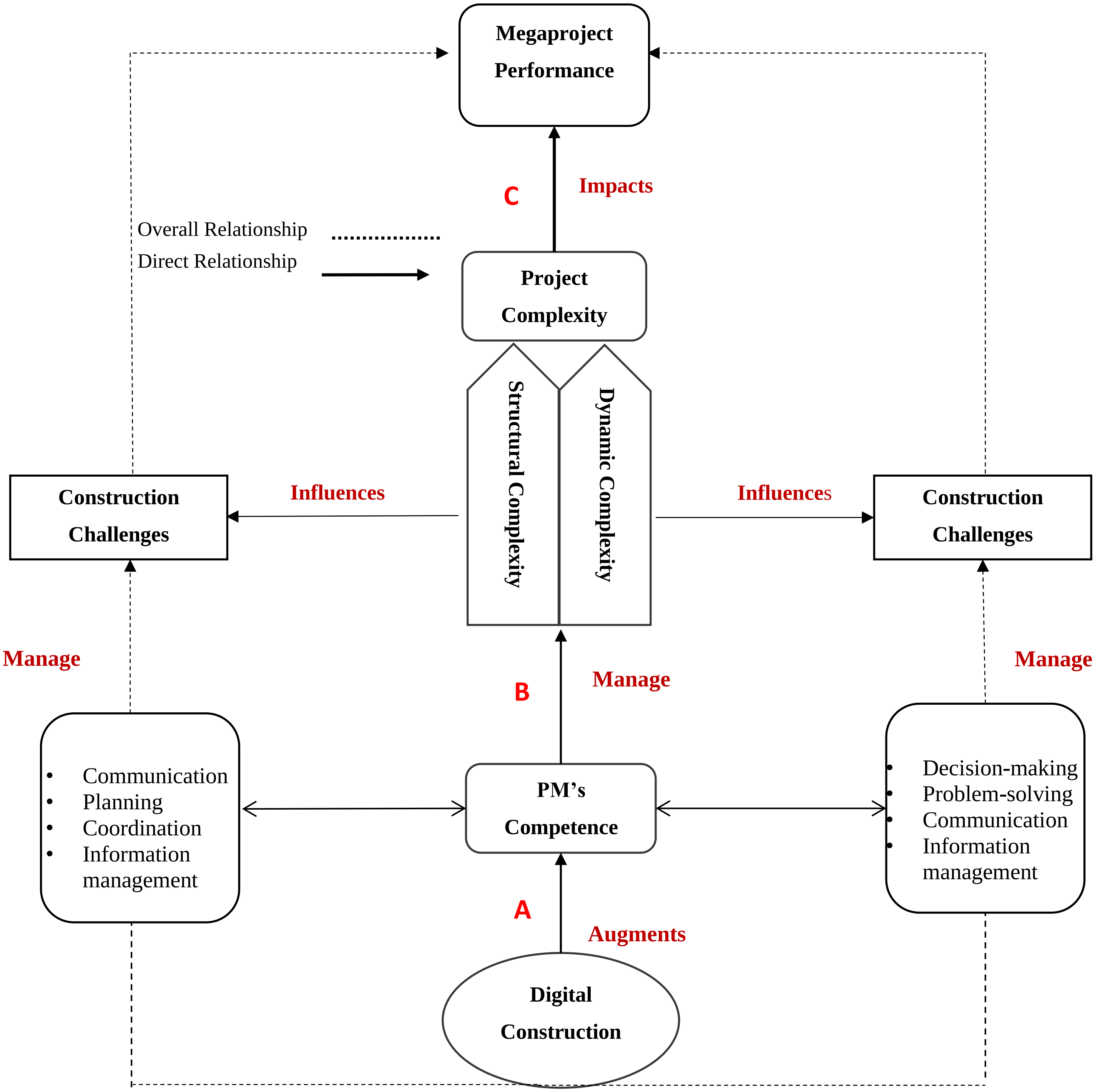

Figure 7.1 Complexity Management Framework

7.2 Hypotheses Development

7.2.1 Hypothesis 1

As discussed, construction project strategies are vital for augmenting project management competence and managing complexity-induced challenges. Based on past study relationships and a pilot study with ten built environment professionals (three academics and seven construction managers), sub-hypotheses reflecting the context from the earlier conceptual framework were proposed.

Several sub-hypotheses were introduced based on the relevant competence factors identified by project managers as crucial for managing infrastructure complexity. This study aims to investigate the general agreement among managers that digital construction enhances competence in managing mega-infrastructure construction. This builds on prior research highlighting the critical influence of appropriate project strategies on augmenting competence during construction to improve outcomes.

Scholars have emphasised the critical influence of manager's competence and complexity on performance, underscoring the significance of project strategy in managing these key themes. Remington and Pollack (2016), Dao et al. (2016), and Nyarirangwe and Babatunde (2021) further emphasised project strategy's role in enhancing competence for complexity management. Abdullahi et al. (2021) reported that while digital construction can potentially support manager competence during construction, substantiating empirical evidence is lacking. Dossick and Neff (2011) advocated using Building Information Modelling (BIM) to enhance coordination, communication, and problem-solving competence. Collectively, these findings suggest that appropriate strategies and digital constructions have the potential to augment competence during construction.

Figure 7.1 illustrates Relationship A, demonstrating that appropriate strategies are necessary to enhance competence. However, further empirical research is required to substantiate digital construction-supporting competence targeted by the first hypothesis. As mentioned, this study focuses on the competence factors identified in Study β, aligned with the framework. One-sample t-tests were used to determine whether the proposed iterations reflect actual construction. The findings indicate a significant difference between the sample and hypothesised means, suggesting that managers generally agree that digital construction has a high influence in augmenting competence during construction.

H_0: $\mu_1 \leq 5$

H_1: $\mu_1 > 5$

Hypothesis $H1_0$: ***Digital construction does not influence project managers' competence***

$H1a_0$ Digital construction does not influence the project manager's communication competence
$H1b_0$ Digital construction does not influence the project manager's planning competence
$H1c_0$ Digital construction does not influence the project manager's coordination competence
$H1d_0$ Digital construction does not support project managers in managing information
$H1e_0$ Digital construction does not influence the project manager's decision-making competence
$H1f_0$ ***Digital construction does not influence the project manager's problem-solving competence***

7.2.2 Hypothesis 2

The project manager's optimal competence in construction has been discussed extensively. Achieving adequate competence requires strategies to enable effective performance. The framework outlines ***Relationship A-B-C***, illustrating that aligning strategies with competence can lead to optimal complexity management competence in mega-infrastructure.

Hypothesis 2 draws on a comprehensive literature review to identify the essential competencies for complex infrastructure projects. Primary hypotheses were formulated based on the competence factors identified in Study β. A preliminary focus group provided additional insights to refine the sub-hypotheses. This study investigated whether digital construction enhances competence in managing mega-construction complexity. With expertise and contextual knowledge, the focus group ensured sub-hypothesis alignment with the study's objectives and questions. The identified constructs formulated sub-hypotheses related to the critical management factors for effectively managing infrastructure complexity from study α. This ensured the relevance and applicability of the proposed method.

In summary, hypothesis two defines optimal competence and identifies effective strategy requirements for augmenting project managers' competence. Sub-hypotheses were developed based on the identified constructs to evaluate the efficacy of digital construction in enhancing mega-construction complexity management competence. A hypothesised mean of four is posited for robust, meaningful statistical tests. As discussed below, hypotheses and sub-hypotheses combine literature insights with expert focus group inputs for accurate contextual reflection.

Hypothesis $H2_0$: *Digital construction does not augment project manager competence to manage complexity during construction*

H_0: $\mu_1 \leq 4$

H_1: $\mu_1 > 4$

Communication

Communication competence is a crucial skill that plays a vital role in construction complexity management, particularly in developing countries (Khattak and Mustafa, 2019). Construction project success depends extensively on seamless information flow among collaborating parties to actualise the final product. This interconnected relationship creates a complex and challenging environment, necessitating prompt and comprehensive information to support participant potential (Wu et al., 2017). However, studies have identified project managers' failure to communicate project information effectively as a primary cause of delays and cost overruns (Gamil et al., 2019). Poor communication during construction can arise from slow information flow, inadequate channels and systems, inconsistent designs, flawed interpretations, continual specification changes, and cultural diversity (Gamil and Rahman, 2017).

To support the team, the operational process relies heavily on extracting information from 2D CAD drawings, specifications, documents, and reports. As a cardinal control point, project managers must efficiently manage and distribute information to avoid conflict and poor output (Senescu et al., 2013). However, complex construction characteristics impede the requirements for effective communication. Complex factors frequently obstruct communication, limiting managers' means of effectively transmitting information. Gamil and Rahman (2017) indicate that inadequate mechanisms, inappropriate systems and channels, ineffective reporting, and flawed feedback hinder construction communication. Along with inherently complex elements, this further restricts the project manager's influence on performance. For instance, a rail project manager communicating with numerous participants across a vast site cannot competently communicate because of inadequate onsite mechanisms.

Nepal et al. (2006) emphasised that effective mechanisms supporting managers in handling schedule pressure influence performance. Numerous mega-infrastructure participants and tasks create complex elements that exert substantial schedule pressure. Consequently, identifying mechanisms to alleviate project tempo is imperative (Mirza and Ehsan, 2017). However, Tai et al. (2009) indicated that the current mechanisms deployed hinder active participant communication. This underscores the need for effective mechanisms to augment active communication and complexity management (Senescu et al., 2013).

While Cheng et al. (2001) suggested that face-to-face communication is the most effective mechanism in infrastructure construction, collective communication with many participants across multiple sites is necessitated during mega-construction, rendering face-to-face communication difficult. El-Saboni et al. (2009) demonstrated the proper mechanisms that influence UAE infrastructure delivery, highlighting electronic system improvements, particularly for scheduling and safety. Effectively managing both is crucial for mega-infrastructure, with project managers scheduling numerous participant work packages while ensuring safety. However, appropriate channels are essential for designing a comprehensive construction communication system irrespective of the mechanism. Project managers must manage multiple channels to disseminate information and mitigate complexity. Nevertheless, inherent complexity poses challenges for establishing channels and systems to support management (Senescu et al., 2013).

Lee and Bernold (2008) reported that inappropriate data and communication channels and inaccurate dissemination hinder construction communication. These challenges are evident in infrastructure, where participants often operate individually, creating barriers that impede managerial influence. Pemsel and Widén (2011) emphasised that project managers should develop competence-bridging channels to create effective construction communication systems. This highlights the need to develop comprehensive approaches aiding communication with many participants, which is crucial for success (Kania et al., 2020). However, the implementation of such systems on mega-sites with demanding, timely, and accurate information requirements for optimal performance remains questionable. Dossick and Neff (2011) suggest adopting an information-driven digital tool approach provides more comprehensive and effective mechanisms. Abdullahi et al. (2021) observed that combining digital tools forms a proactive strategy enabling communicative competence amid complexity. Nevertheless, empirical reinforcement of the influence of digital construction on communication competence is lacking. Thus, this study proposes that digital construction facilitates effective communication and enables managers to address complexity-induced challenges during infrastructure construction, as reflected in Hypothesis 2, assessed through the following sub-hypotheses:

Hypothesis H2a$_0$: Digital Construction does not support project managers in managing communication complexity during infrastructure construction.

H2.1a$_0$ Digital construction does not provide a suitable mechanism for concurrent interactions with numerous participants.
H2.2a$_0$ Digital construction does not provide an appropriate system for active multi-site participant interaction.
H2.3a$_0$ Digital construction does not provide a channel for fostering timely on-site response during construction.
H2.4a$_0$ Digital construction does not support specification change transmission through the reporting systems.
H2.5a$_0$ Digital construction does not provide robust feedback systems for accurate multi-drawing instruction transmission.
H2.6a$_0$ Digital construction does not enable the timely distribution of dispersed team instruction.

Planning

Construction projects are inherently complex, necessitating meticulous planning and management to achieve successful outcomes. Effective planning is vital in managing complexity by ensuring that projects are completed within the proposed budget, schedule, and quality standards. Peurifoy et al. (2018) emphasise the primary role of the project manager in developing a comprehensive outline and defining milestones and methods to achieve efficiency. However, mega-infrastructure projects present unique challenges as complexity elements interact, often hindering adequate planning and optimal courses of action (Collyer et al., 2010). Hence, effective planning is crucial for managing complexity.

According to Kerzner (2017), effective planning enables predicting and reducing uncertainty, optimising efficiency, defining objectives, and monitoring progress. Planning involves scheduling, budgeting, forecasting, procedures, and standards. Faniran et al. (1998) identified extensive preexecution planning, reduced emphasis on monitoring schedules, and increased focus on implementation plans as construction project planning success factors. However, mega-infrastructure managers face constraints in defining plans and processes owing to numerous tasks, uncertainty, varied drawings, and ambiguity (Nguyen et al., 2018). Nevertheless, planning remains critical for infrastructure and project management (Shehu and Akintoye, 2009b). However, this study reiterates how project managers could plan infrastructure in a complex and dynamic environment, such as a mega construction site, where managers have minimal project knowledge initially.

A well-defined project scope, goals, objectives, deliverables, and timelines are essential for the success of megaprojects. Detailed plans should outline each task, resource schedule, optimised allocation, and smooth progress (Kerzner, 2017). Effective communication through regular updates and reports is paramount (Mochal et al., 2011). Efficient resource plans are indispensable, considering the availability and allocation to prevent conflicts and ensure timely completion (Collyer et al., 2010), enabling smooth execution.

Pellerin and Perrier (2019) emphasise that managers employ systematic, logical planning methods for effectiveness. Russell et al. (2015) demonstrate the last planner system's efficacy in managing uncertainty and minimising variations. Sacks et al. (2010) propose BIM-enabled software for planning. However, Lock (2017) argued that software can overwhelm managers with limited time. This study advocates adopting digital construction, enabling managers to leverage tools and address software limitations, enhancing planning, and navigating complexity challenges to optimise performance. Consequently, we propose Hypothesis 2b and its sub-hypotheses on the digital construction's planning augmentation role.

Hypothesis $2b_0$: Digital construction does not augment project managers to effectively plan infrastructure construction for complexity management

$H2.1b_0$ Digital construction does not enable managers to explore different planning approaches for managing sequence rigidity during construction.

$H2.2b_0$ Digital construction does not permit managers to break down the project scope into workable components.

$H2.3b_0$ Digital construction constraints managers from scheduling workers on every project size

$H2.4b_0$ Digital construction does not enable project managers to forecast the resources required during construction through accurate budget estimation.
$H2.5b_0$ Digital construction does not support managers in implementing measures to achieve the defined quality objectives when unfamiliar construction methods are used.

$H2.6b_0$ Digital construction does not provide managers with a platform to monitor a project's vast supply chain during infrastructure construction.

Coordination

Mega-infrastructure projects present unique coordination and resource allocation challenges owing to the complexity of multiple professionals and significant resources. Effective coordination and allocation are critical for achieving goals and ensuring success (Zegarra and Alarcón, 2019). However, numerous tasks, diverse workers, and resource-intensive operations make this challenging (Abdullahi et al., 2021). Coordination strategy implementation is integral to mega-project success (Zegarra and Alarcón, 2019).

The importance of coordination in performance and productivity is significant (Ochieng and Hughes, 2013). Extensive research has demonstrated a positive relationship between effective coordination and successful delivery (Zegarra and Alarcón, 2019). However, complexity often poses coordination implementation challenges for managers. Key coordination activities include optimal resource requirement estimates, detailed method selections with stakeholder input, scheduling, budgeting, progress reporting, change order and discrepancy procedures, and identifying delays (ASCE, 2012; Jha and Iyer, 2006).

Although managers rely on meetings, plans, and contracts for coordination, as convenience often dictates their choice over effectiveness (Chang and Shen, 2014). In mega-projects, numerous meetings and detailed plans impede accuracy (Qazi et al., 2016). This study proposes digital construction as a responsive complexity-management approach, using technologies to enhance mega-project coordination and resource allocation.

Coordination is considered insignificant because it relies solely on managers. However, other studies have confirmed a strong correlation with project success (Chang and Shen, 2014; Jha and Iyer, 2006). Few studies have examined coordination complexity management during construction projects. Previous research has proposed last planner systems for coordination (Koskela et al., 2002), integrated project delivery (Serginson et al., 2013), coordination factor identification (Alaloul et al., 2016), and BIM approaches (Dossick and Neff, 2011). Despite these proposed strategies have been put forward, certain limitations persist. This study hypothesised that digital construction could support resource coordination and contain complexity, evaluated through the following sub-hypotheses.

*Hypothesis 2*c_0*: Digital construction does not support project managers to coordinate project resources during mega infrastructure construction*

*H2.1*c_0 *Digital construction does not ensure that numerous site activities that form a workflow are coordinated while relying on other project inputs.*

*H2.2*c_0 *Digital construction does not support managers in developing a comprehensive work breakdown structure to cope with the enormous scope of the project.*

*H2.3*c_0 *Digital construction does not support managers in integrating construction activities to complement the available resources on large construction sites.*

*H2.4*c_o *Digital construction does not support managers in scheduling equipment for optimal usage at large construction sites.*

*H2.5*c_o *Digital construction does not support work program sequencing among numerous on-site teams.*

*H2.6*c_o *Digital construction does not enable easy work package delegation to numerous workers on-site.*

Information Management

The construction industry relies heavily on transforming information such as drawings and specifications into physical products. Effective information management plays a critical role in complexity management by coordinating schedules, resources, and tasks. According to the Association for Project Management (2019), information management involves collecting, storing, curating, disseminating, archiving, and destroying project information throughout the project lifecycle. Project managers are responsible for construction, ensuring appropriate information communication for informed, cost-efficient decision-making ((Harris et al., 2021), and learning from experiences (Ekrot et al., 2016).

Proper information planning, organisation, and dissemination are crucial for participants to understand the schedule and specification changes, avoid duplication, and prevent deviations. Back and Moreau (2001) proposed information management functions, including creating, capturing, manipulating, exchanging, and storing information. This forms the basis for effective strategies managers adopt for smooth information flow during construction.

Traditionally, information has been created and disseminated through drawings, communication, and work breakdown structures. However, owing to process complexity, technological tools are increasingly being used to support managers in information management. Although technology has significantly improved construction data dissemination, managers still face challenges in large-scale infrastructure projects involving numerous participants, tasks, vast information, and varying quality (Winch, 2010). This highlights the need for effective mediums in which managers can efficiently fulfil information functions for performance and success.

Studies have shown that digital tools such as BIM and cloud computing offer information management solutions. However, Back and Moreau (2001) argued that digital tools sometimes have limitations. Entities should select adaptable strategies for their respective domains. This study proposes that project managers can manage infrastructure construction information better using digital construction practices. Hypothesis 2d and its sub-hypotheses validate this proposition.

Hypothesis $2d_0$: Digital construction supports project managers in managing information effectively during mega-infrastructure construction.

$H2.1d_0$ Digital construction does not support managers in gathering relevant information for accurate time and budget estimation.

$H2.2d_0$ Digital construction does not provide a shared data environment as a holistic medium for simultaneously distributing specification changes to subcontractors.

$H2.3d_0$ Digital construction does not enable managers to gather real-time information on construction challenges from numerous project teams on-site.

$H2.4d_0$ Digital construction does not ensure that managers accurately store project information changes over an extended period.

$H2.5d_0$ Digital construction constraints managers from accessing project information from multiple site locations to resolve RFIs

H2.6d$_0$ Digital construction promotes redundant information from numerous information sources on-site.

Decision-making

Complexity primarily arises from uncertainty, hindering informed decision-making due to the lack of information during construction (Belay et al., 2017). Competent decision-making is a mega-project success factor. This involves identifying and selecting potential alternatives based on managers' discretion. However, with dynamic complexity characterised by uncertainty, managers struggle to make contingency decisions to restore performance when presented with numerous options but few constraints (Winch, 2010). Information scarcity makes choosing suitable options challenging (Geraldi and Adlbrecht, 2008).

Tversky and Kahneman's (1974) prospect theory explains uncertain, complex decision-making. Information framing and evaluation are crucial for effective decision-making (Tversky and Kahneman, 1974). The process combines activities to ensure the selection of the best solution while constraining biases (Zavadskas et al., 2014). Parth (2013) investigated the adoption of classical decision-making models to facilitate critical decision-making. However, the practical application of these models is criticised for unrealistic assumptions that are misaligned with construction reality.

In response, Książek et al. (2015) recommended algorithms and multi-criteria analysis to improve decisions. Louis and Dunston (2018) emphasised the integration of digital tools to enhance construction decision-making. Building on this, this study advocates integrating digital technologies to enable project managers to make precise decisions amid complexity and uncertainty. Hypothesis 2e asserts that digital construction facilitates proactive decision-making during construction.

Hypothesis 2e$_0$: Digital construction does not support managers in making decisions that curtail complexity during mega infrastructure construction.

H2.1e$_0$ Digital construction restricts managers from analysing decisions from the numerous project participants' viewpoint

H2.2e$_0$ *Digital construction constraints managers from gathering relevant information for decision-framing in the face of unforeseen circumstances*

H2.3e$_0$ *Digital construction does not enable managers to identify alternative decisions that could be adopted to manage the project tempo*

H2.4e$_0$ *Digital construction confines managers from making decisions based on the available information gathered from multiple locations onsite*

H2.5e$_0$ *Digital construction does not support managers to transmit decisions to the project participants in real-time*

H2.6e$_0$ *Digital construction does not enable decision implementation at multiple locations to curtail the uncertainty effect.*

H2.7e$_0$ *Digital construction does not provide a platform for managers to monitor the implications of decisions in cognition of the revised project baseline.*

Problem-solving

Infrastructure development often lacks sufficient information on potential construction challenges, making uncertainty a defining characteristic of project progression. This requires project managers to provide immediate and unpredictable solutions to complex issues (Davis et al., 2018). Effective construction problem-solving necessitates an understandable language for all participants. However, mega-infrastructure complexity makes articulating problems and solutions difficult for managers (Moradi et al., 2020). Construction problems typically arise from uncertainty, errors, inadequacy of information, ambiguity, and safety mishaps (Love et al., 2016). In such scenarios, managers must promptly mitigate the situation and prevent deviations.

The prevailing problem-solving approach is reactive and structured. Davis et al. (2018) employed the Johari window to investigate construction problem-solving processes, recommending a systematic approach - problem identification and definition, comprehensive solution selection, solution proposal, implementation, and impact assessment. This reinforces the idea that unknown problems can be effectively managed through the construction's inherent structured process. Turner (2009) suggested a construction-specific cycle-defining problem, determining causes, generating ideas, selecting suitable solutions, and acting. This enhances the effectiveness of organisational problem-solving.

Davis et al. (2018) emphasise leveraging innovative media to support construction problem-solving. Technology is a reactive medium owing to its effectiveness in information management. Dossick and Neff (2011) highlight Building Information Modelling's (BIM) visualisation capability improvement of problem-solving processes. However, individual tool implementation may have limitations in executing construction problem-solving. This study proposes integrating tools into a comprehensive strategy to enhance project management competence in managing mega-infrastructure complexities. Furthermore, this study empirically establishes that digital tool integration enables managers to implement problem-solving processes efficiently, as hypothesised.

Hypothesis 2f_0: Digital Construction will not enable project managers to solve complex challenges during infrastructure construction.

H2.1f_0 Digital construction unable managers to perceive potential problems that may occur from project specification change

H2.2f_0 Digital construction does not support managers in gathering information from multiple site locations when problems occur.

H2.3f_0 Digital construction does not enable rigid work sequence evaluation to identify viable solutions to challenges arising from site topography.

H2.4f_0 Digital construction does not support managers in generating workable solutions to manage the uncertainty effects of task difficulty.

H2.5f_0 Digital construction constrains the implementation of viable solutions that may curtail the negative impact of the uncertainty stemming from untried construction methods.

H2.6f_0 Digital construction does not support managers in evaluating the positive impact of the selected solutions on managing scope uncertainty.

7.2.3 Hypothesis 3

The proposed hypotheses examine the relationship between H1 and H2 in construction project management. Studies have consistently shown that adopting the appropriate project strategy significantly influences managers during construction (Remington and Pollack, 2016). Notably, management competence has been found to correlate positively with project success, particularly in complex settings (International Centre for Complex Project Management, 2012)

Moreover, research has highlighted the negative impact of complexity on construction project success (Luo et al., 2016) and the importance of technical competence in effectively managing complexity (Dias et al., 2014). Remington and Pollack (2016) also stressed the significance of project strategy in developing competence, suggesting that enhancing competence through strategy can enable effective complexity management (Dao et al., 2017). Kermanshachi et al. (2021) recommended identifying strategies empowering managers to assert themselves effectively during mega-construction for efficient complexity management.

Growing literature emphasises the potential of digital tools to address construction challenges across the project lifecycle (Woodhead et al., 2018). Accordingly, this study investigates the interrelationship between digital construction and project manager competence, precisely their ability to manage infrastructure construction complexity effectively. The degree of this interrelationship determines the extent to which digital construction enhances competence in handling complexity. If a strong correlation is established, this research can confidently advocate adopting digital construction to enhance competence in managing complexity in mega-infrastructure projects, particularly in developing countries. Analysing this crucial relationship contributes to attaining objectives four and five. Hypothesis 3 underwent a thorough analysis to yield valuable insights, enhancing the overall understanding of the outlined research questions and objectives.

Hypothesis $H3_0$: There is no positive relationship between digital construction influence on project manager's competence and digital construction supporting project managers to manage infrastructure construction complexity

7.3 Scale Reliability

In this study, two scales were used to assess the reliability of the measurements. Hypothesis 2, which explored a seven-point rating scale, demonstrated a high level of internal consistency, as evidenced by Cronbach's alpha coefficient of 0.926. Similarly, the data collected to test Hypothesis 1 exhibited high internal consistency, with a Cronbach's alpha coefficient of 0.953. These findings indicate that both scales share a common underlying construct and consistently correlate with all the items on the scale (Field, 2009). In social science research, Cronbach's alpha is widely used to evaluate scale reliability (Bonett and Wright, 2015). These results provide reassurance as they confirm the reliability and suitability of the constructed scales for use within a similar study context.

Furthermore, it is noteworthy that the obtained Cronbach's alpha coefficients surpassed the recommended threshold of 0.6, with both scales reaching substantial values (Tavakol and Dennick, 2011). Values between 0.7 and 0.9 are considered satisfactory to indicate good internal consistency without redundancy (Bland and Altman, 1997), suggesting that the scales effectively captured the necessary information to support the study's findings.

This study achieved robust and reliable measurements by employing scales with high internal consistency, enhancing the credibility and validity of the findings and instilling confidence in the researcher's ability to draw accurate conclusions. Scale reliability ensures that the data collected are consistent and dependable, thus strengthening the overall quality of the study (Heale and Twycross, 2015).

7.4 Primary Research Data Analysis Presentation

This section provides an overview of the empirical findings, defines the demographic data, and explains the inferential statistics employed in hypothesis testing. Hypotheses one and two were assessed using a one-sample t-test, while hypothesis three was examined using Pearson's correlation coefficient r to measure the strength of the relationship between variables one and two. The resulting outcomes are presented in tables that display the one-sample test results and multiple correlation analysis.

7.4.1 Digital Construction Influence

How frequently does your company rely on technological tools during project construction?

The first question aimed to determine the extent of digital construction tool use during mega-infrastructure development in Nigeria. Examining empirical adoption levels ascertained the frequency of use in such projects. Project managers provided an ordinal scale response ranging from "always" (5) to "never" (1). The data analysis in Table 7.2 showed a mean score of 2.52 with a 1.004 standard deviation above the mean. However, the equidistant nature of the mean does not offer sufficient insight into the precise usage frequency.

Table 7.1 Digital Tool Usage during Construction

	N	Mean	Std. Deviation	Skewness	
	Statistic			Statistic	Std. Error
How frequently does your company rely on technological tools during project construction	141	2.52	1.004	-.114	.204
Valid N (listwise)	141				

A closer examination revealed that 21.3% and 20.6% of project managers reported "always" and "frequently" using digital tools, respectively. Conversely, 9.2% and 2.1% indicated "rare" and "never" usage during construction (Figure 7.1). This suggests occasional digital tool employment by project managers in Nigeria for mega infrastructure construction. These results align with Blanco et al. (2017), where they emphasised digital tool prevalence in large-scale construction without specifying a geographical region. In contrast, this study focuses exclusively on Nigerian mega-construction sites, providing valuable localised insights.

This finding further supports the site visits in Study γ, where digital tool utilisation during construction was observed. Sporadic usage occurs at Nigerian mega-construction sites. These findings emphasise the necessity for increased investment in these tools, allowing project managers to effectively manage the intricate challenges that arise in Nigerian mega-construction projects. Enhancing availability and adoption can augment managerial abilities to navigate and overcome the associated complexities.

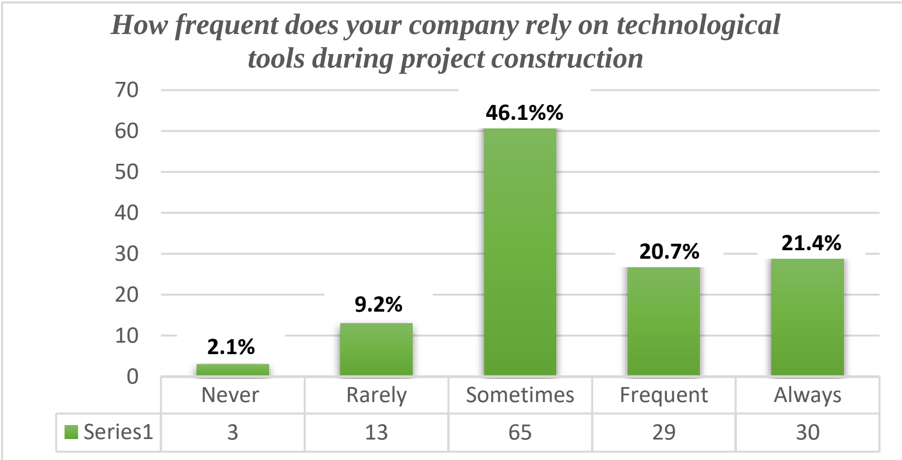

Figure 7.2 Digital Tools Usage on Construction Sites (Source: Own Study)

How comprehensive is your company's digital construction strategy?

The second question assessed the comprehensiveness of the digital construction strategy implemented on Nigerian mega-construction sites. As noted, Kang et al. (2016) and Sacks et al. (2020b) highlighted integrating BIM and other digital tools as potentially beneficial for supporting project managers. This underscores the need to investigate strategy comprehensiveness. The measurement scale (Figure 7.2) evaluated adoption and utilisation, ranging from "Not at all", denoting minimal to no usage, to "Partially" and "Moderately", suggesting limited or moderate adoption, "Substantially" signifying extensive incorporation across processes, and "Extremely" indicating comprehensive utilisation encompassing all aspects.

The analysis revealed a 3.35 mean score and standard deviation of 1.015, indicating comprehensive digital tool utilisation. A considerable proportion of the respondents expressed moderately comprehensive strategies. However, 24.1% and 14.9% reported partial to non-comprehensive strategies, suggesting room for improvement and further on-site adoption. These findings underscore the encouragement of additional digital tools during the construction of Nigerian mega-infrastructure. Moreover, moderate usage may stem from limited infrastructure development capital, which hinders advanced tool investment. Thus, addressing financial constraints and promoting adoption can enhance strategies and improve Nigerian project outcomes.

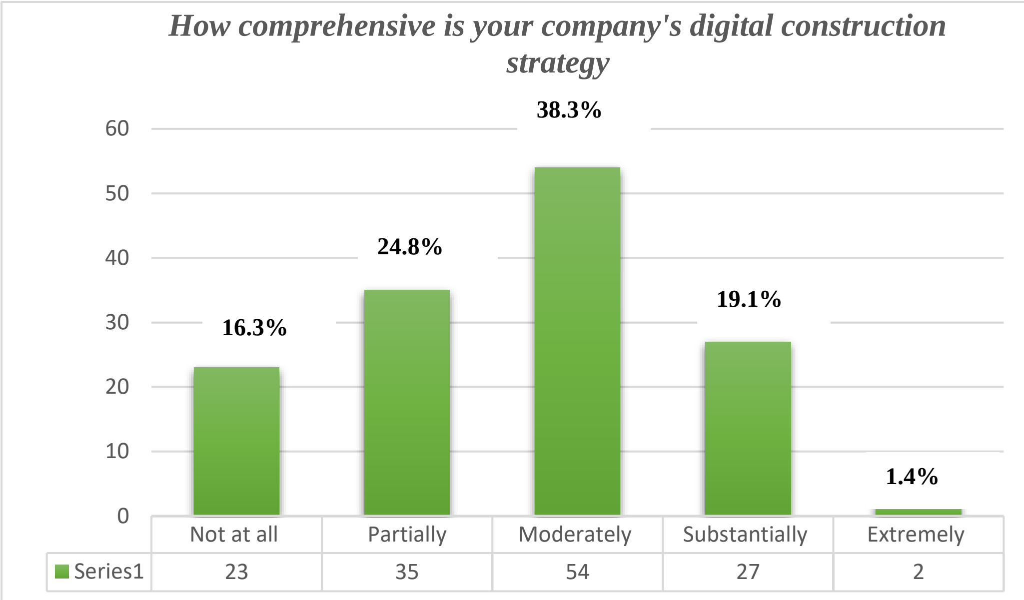

Figure 7.3 Digital Construction Comprehensiveness in Nigeria (Source: Own Study)

To what extent does adopting digital construction enhance project management competence during construction?

To address Research Question 3, hypothesis one was formulated, suggesting that digital construction utilisation enhances project manager competence during construction, as depicted in the conceptual framework's Relationship A (Figure 7.1). The sub-hypotheses derived from the prominent competence factors identified in Study β are listed below and statistically evaluated based on the collected data in Table 7.2.

Table 7.2 Statistical Results for Hypothesis 1

H1	Competence Factor	Mean ($1 < y < 10$)	S. D	Calculated-T ($y \geq 1.6558$ one-tailed critical t)	$p < 0.05$	Remark (H_0: $\mu_1 \leq 5$)
H1a	Communication	7.794	1.861	17.826	0.00	Rejected
H1b	Planning	8.021	1.667	21.524	0.00	Rejected
H1c	Coordination	8.241	0.139	23.244	0.00	Rejected
H1d	Information Management	7.716	1.758	18.348	0.00	Rejected
H1e	Decision-making	7.695	1.905	16.808	0.00	Rejected
H1f	Problem-Solving	7.525	1.973	15.193	0.00	Rejected

Table 7.2 presents the one-sample t-test results for Hypothesis 1 obtained through inferential statistics. The mean scores, standard deviations, calculated t-values, and p-values are reported for

each competence factor. The null hypothesis (H_0: $\mu 1 \leq 5$) was rejected for all factors, providing substantial evidence of the statistical significance of the observed means.

For communication (H1a), project managers reported a mean of 7.794 with a standard deviation of 1.861. The calculated t-value of 17.826 significantly exceeded the one-tailed critical value with a p-value of 0.00. This rejection suggests that project managers perceive themselves as highly communication-competent, utilising digital construction for mega-construction. This analysis supports digital construction and enhances stakeholder communication and collaboration effectiveness during construction. Similarly, for planning (H1b), project managers reported an 8.021 mean and 1.667 standard deviation. The calculated t-value of 21.524 significantly surpassed the critical value with a p-value of 0.00. This rejection proves that digital construction positively influences perceived planning competence, improving construction activity planning and organisation and enhancing outcomes.

Additionally, coordination (H1c) yielded an 8.241 mean and a remarkably low standard deviation of 0.139. The calculated t-value of 23.244 significantly exceeded the critical value, with a p-value of 0.00. This rejection indicates that digital construction is perceived as a valuable tool for enhancing coordination competence during mega-construction, optimising resource allocation, streamlining workflow, and mitigating complexity. Moreover, information management, decision-making, and problem-solving rejected the null hypothesis, with calculated t-values exceeding the 1.657 one-sided critical value and 0.00 p-values. These robust findings indicate that project managers consider themselves highly competent in these areas, utilising digital construction, enhancing information management and utilisation, informed decision-making, and complex problem resolution during mega-construction.

The empirical findings strongly support the conceptual framework of Relationship A. Research has consistently demonstrated the project strategy's crucial competence enhancement role throughout development. Scholars such as Remington and Pollack (2016) have advocated responsive strategies to improve delivery and competence. Similarly, studies by Dao et al. (2016) and Nyarirangwe and Babatunde (2021) emphasise adopting appropriate strategies to manage complexity effectively.

Regarding digital construction strategy, Woodend et al. (2018) demonstrated its effectiveness, highlighting the positive performance impact. Kim and Chi (2020) propose applying digital construction to enhance coordination, while Zhong et al. (2017)) assert digital tools improve construction communication. Additionally, Dossick and Neff (2011) advocated BIM use to augment communication and problem-solving. Moreover, Chapter 6 observed digital construction support during Nigerian mega-construction.

Collectively, these studies underscore the importance of strategy in supporting project managers yet do not specifically examine general opinions of digital construction. This study addresses this gap by providing empirical evidence for widespread project manager agreement that digital construction significantly enhances competence. This ground-breaking study is the first to capture the digital construction perspective in Nigeria. The statistical results reflect project managers' views with 95% confidence rather than mere chance. Moreover, the inferential results strengthen the conceptual framework's Relationship A support, providing concrete manager-perspective evidence for deploying digital construction in Nigeria.

7.4.2 Inferential Statistics for Hypothesis Two

$H2_0$ Digital construction does not augment project management competence to manage complexity-induced challenges during infrastructure construction

This section examines the extent to which project managers perceive digital construction to enhance their competence and effectively manage complexity. Six hypotheses, along with their corresponding sub-hypotheses, were formulated to investigate whether the mean of the sample population surpasses the observed mean of four, which indicates relevance. The sub-hypotheses and their corresponding statistical results are discussed below:

H_0: $\mu_1 \leq 4$

H_1: $\mu_1 > 4$

H2a: Communication

Hypothesis $H2a_0$: Digital Construction does not support project managers in managing communication complexity during infrastructure construction

One-sample t-tests assessed project manager agreement on the effectiveness of digital construction in enhancing communication competence for mega-construction complexity in Nigeria. The results in Table 7.3 indicated significant findings across dimensions. For H2.1a, project managers strongly agreed (mean = 5.96) that adopting digital construction provides effective mechanisms for simultaneous interaction with multiple participants. The calculated t-value (18.900) demonstrates a substantial difference between the observed and expected means. The p-value (0.001) indicated high statistical significance, providing robust evidence that digital construction enables effective diverse participant communication and addresses associated complexity challenges.

Similarly, for H2.2a, project managers agreed (mean = 5.81) that digital construction offered suitable systems for active multi-site participant interaction. The calculated t-value (17.625) and p-value below 0.05 confirmed this agreement's statistical significance. The analysis of H2.3a revealed agreement (mean = 6.10) that digital construction provides communication channels that foster timely on-site responses during mega-construction. The calculated t-value (21.143) and p-value (0.001) indicated a high statistical significance, rejecting the null hypothesis.

Likewise, for H2.4a, project managers agreed (mean = 5.79) that digital construction significantly improved specification change reporting systems. The calculated t-value (14.727) and p-value (0.001) demonstrated strong statistical significance, thus rejecting the null hypothesis. Examining H2.5a showed agreement (mean = 6.18) that digital construction enhances the robustness of the feedback system for transmitting accurate drawing instructions. The calculated t-value (28.110) and p-value (0.001) indicated a high statistical significance, rejecting the null hypothesis. Furthermore, project managers agreed (mean = 5.88) that digital construction improved the timely instruction distribution in mega-construction. The calculated t-value (19.964) and p-value (0.001) demonstrated strong statistical significance, thus rejecting the null hypothesis.

The analysis revealed general project managers' agreement on digital construction's effectiveness in enhancing communication competence across dimensions. The null hypothesis rejections with high statistical significance prove that digital construction facilitates effective communication, improves reporting, enhances feedback, and enables timely instruction distribution in Nigerian mega-construction projects.

Table 7.3 Inferential statistical analysis of Hypothesis 2a.

H2a	Communication (construct)	Mean ($1 < y < 7$)	S. D	Calculated-T ($y \geq 1.6558$ one-tailed critical t)	$p < 0.05$	Remark ($H_0: \mu_1 \leq 4$)
H2.1a	Communication mechanism	5.96	1.230	18.900	0.001	Accepted
H2.2a	Communication system	5.81	1.218	17.625	0.001	Accepted
H2.3a	Communication channel	6.10	1.179	21.143	0.001	Accepted
H2.4a	Reporting system	5.79	1.447	14.727	0.001	Accepted
H2.5a	Robust feedback system	6.18	0.923	28.110	0.001	Accepted
H2.6a	Timely instruction distribution	5.88	1.118	19.964	0.001	Accepted

H2b: Planning

Hypothesis 2b: Digital construction does not augment project manager's to effectively plan infrastructure construction for complexity management

One-sample t-tests assessed project manager agreement on the effectiveness of digital construction in enhancing planning competence for scheduling and resource allocation during Nigerian mega-construction. The results in Table 7.4 provided significant insights. Starting with H2.5b, project managers strongly agreed (mean = 6.18) that digital construction enhances enforcement of quality measures when dealing with unfamiliar methods. The calculated t-value (28.110) indicated a significant observed versus expected mean difference, thus rejecting the null hypothesis with a p-value of 0.001. This highlights the importance of digital construction in enforcing quality standards and managing unfamiliar method complexities.

For H2.1b and H2.2b, project managers perceived digital construction as providing more effective tools and processes for planning and breaking down the project scope into manageable components. The calculated t-values significantly exceeded the critical values, with p-values below 0.05, leading to null hypothesis rejection. This indicates that digital construction enables the development of planning and scheduling approaches that effectively manage the complexity from rigidity and extensive scope. This aligns with Sacks et al.'s (2020) digital twin construction (DTC) concept, emphasising BIM, lean production, data acquisition, and integration of Industry 4.0. The findings support digital construction and provide unique planning and scheduling techniques for mega-construction.

Regarding H2.3b, H2.4b, and H2.6b, the calculated t-values significantly exceeded the critical values with p-values below 0.05, leading to null hypothesis rejection. This demonstrates significant observed versus expected mean differences, indicating that project managers perceive digital construction as valuable for managing the complexity in resource allocation, cost control, and timely instruction distribution during mega-construction. This supports the idea of enhanced worker scheduling, resource forecasting, and supply chain monitoring abilities by utilising digital construction during Nigerian mega-construction. Jiang et al. (2015) presented a similar scenario where digital construction enabled labour scheduling, monitoring, productivity tracking, and improved data for contract negotiation through a mobile system integrating GPS and GIS for labour consumption measurement. This novel concept aligns with H2.3b's findings, indicating enhanced worker scheduling and monitoring abilities with digital construction during mega-construction.

Irizarry et al. (2013) proposed an integrated framework utilising 3D modelling and GIS for proactive supply chain management. This study emphasises the need for further advancements in digital construction that enable proactive supply chain management. Nigerian project managers believe that digital construction supports the management of the vast supply complexity during mega-construction. Null sub-hypothesis rejections demonstrated 95% confidence that the results were not due to chance.

Overall, the analysis revealed project managers' agreement on digital construction's effectiveness in enhancing planning competence across dimensions. Null hypothesis rejections with high statistical significance provide robust evidence of the value of digital construction in improving quality measures, developing effective planning and scheduling approaches, and managing complexity in resource allocation, cost control, and instruction distribution during Nigerian mega-construction projects.

Table 7.4 Statistical results for hypothesis 2b

H2b	Planning (construct)	Mean (1 < y < 7)	S. D	Calculated-T ($y \geq 1.6558$ one-tailed critical t)	$p < 0.05$	Remark (H_0: $\mu_1 \leq 4$)
H2.1b	Different planning approaches	4.94	1.616	6.932	0.001	Accepted
H2.2b	Breakdown project scope	4.91	1.984	5.476	0.001	Accepted
H2.3b	Schedule workers	4.72	1.830	4.649	0.001	Accepted
H2.4b	Resource forecast	6.13	0.992	25.474	0.001	Accepted
H2.5b	Enhance quality measures	6.18	0.923	28.110	0.001	Accepted
H2.6b	Supply chain management	5.88	1.118	19.964	0.001	Accepted

H2c: Coordination

Hypothesis 2c$_0$: Digital construction does not support project managers to coordinate project resources during mega infrastructure construction

A one-sample t-test assessed the impact of digital construction on resource coordination by project managers in large-scale construction. As shown in Table 7.5, the findings are significant for H2.4c, H2.5c, H2.2c, H2.3c, and H2.1c. In H2.4c, managers widely accepted digital construction to delegate work packages and scheduling equipment. The calculated t-value (16.807) indicated a significant difference between the observed and expected means, thus rejecting the null hypothesis with high statistical significance. This finding provides robust evidence that digital construction supports resource coordination.

Similarly, managers agreed that digital construction effectively facilitates the development of comprehensive work breakdown structures, as indicated by H2.2c results. The calculated t-value (23.919) demonstrated a significant difference between the means, with high statistical significance. H2.3c also shows that digital construction effectively supports the integration of construction activities. The calculated t-value (23.124) exceeded the critical value, thus rejecting the null hypothesis with strong statistical significance.

Regarding workflow monitoring efficiency, managers agreed that digital construction enables efficient monitoring, as shown by the results of H2.1 c. The calculated t-value (13.327) indicated a significant difference between the means, rejecting the null hypothesis with high statistical significance. Furthermore, for H2.4c and H2.6c, managers recognised the value of digital construction in coordinating and scheduling equipment and managing virtual teams at mega-construction sites. The calculated t-values provided robust evidence of null hypothesis rejection with high statistical significance.

Previous studies have supported these findings. Zegarra and Alarcón (2019) emphasised the importance of resource coordination as a large-scale construction project success factor. Jha and Iyer (2006) and ASCE (2012) highlighted aspects involved in effective coordination. However, prevalent methods fall short of complexity management requirements during mega-construction. This study further builds upon these suggestions and empirically establishes manager agreement that adopting digital construction enhances coordination competence in managing vast resources during mega-construction. The findings also validate the study's notion of utilising digital construction to enhance the coordination of site activities, develop comprehensive work breakdowns, and integrate activities to effectively manage construction complexity.

Overall, the findings align with research that emphasises resource coordination as a critical construction project success factor. By adopting digital construction, managers can address complexity-associated challenges and manage vast on-site resources effectively. Digital tools and technology integration enhance coordination competence, enabling informed decisions, optimised allocation, and successful mega-construction execution.

Table 7.5 Inferential statistics results supporting H2c

H2c	**Coordination (construct)**	**Mean ($1 < y < 7$)**	**S. D**	**Calculated-T ($y \geq 1.6558$ one-tailed critical *t*)**	**$p < 0.05$**	**Remark (H_0: $\mu_1 \leq 4$)**
H2.1c	Efficiently monitor workflow	5.50	1.340	13.327	0.001	Accepted
H2.2c	Develop a comprehensive work breakdown structure	6.01	0.996	23.919	0.001	Accepted
H2.3c	Integrate construction activities	6.08	1.042	23.124	0.001	Accepted
H2.4c	Schedule equipment	6.03	0.919	26.861	0.001	Accepted
H2.5c	Subcontractors’ management	5.35	1.127	16.807	0.001	Accepted
H2.6c	Virtual team management	5.50	1.296	13.708	0.001	Accepted

H2d: Information Management

Hypothesis 2d: Digital construction augments project managers' ability to effectively manage information during mega-infrastructure construction.

A one-sample t-test assessed project managers' consensus on the effectiveness of digital construction in supporting mega-construction information management in Nigeria. As shown in Table 7.6, these findings are significant. For H2.5d, managers widely agreed that digital construction enables effective Request for Information (RFI) resolution by providing multi-location access. The calculated t-value (24.195) indicates a significant difference between the observed and expected means, leading to null hypothesis rejection with a p-value of 0.001. This aligns with research advocating collaborative BIM-based platforms to enhance RFI resolutions (Keskin et al., 2021). Abdullahi et al. (2021) also highlighted digital tools facilitating RFI resolution through digital construction in mega-construction sites. H2.5d outcomes further underscore the use of digital construction to provide information that mitigates RFI complexity. Moreover, this study contributes by capturing managers' perspectives on enabling RFI solutions through digital construction practices in Nigerian mega-constructions.

Furthermore, for H2.1d and H2.3d, the managers agreed that digital construction facilitates real-time challenge information gathering from multiple teams and accurate resource estimation. The calculated t-values significantly exceeded the critical value, and the p-values were below 0.05, supporting null hypothesis rejection. This aligns with studies emphasising the effectiveness of digital tools and technology in enhancing real-time construction information gathering and sharing (Sacks et al., 2016; Sacks et al., 2020). Specifically, Sacks et al. (2016) highlighted the efficacy of BIM protocols in gathering information during mega-construction. Sacks et al. (2020) emphasised digital tools and technology's positive real-time information-sharing impact. Building on these studies, the current research substantiates that digital construction enhances information gathering and distribution among project managers in mega Nigerian construction sites, with complexity influenced by size and resources.

Similarly, for H2.2d, H2.4d, and H2.6d, the calculated t-values showed significant differences between the observed and expected means, leading to a null hypothesis rejection at the 0.001 significance level. This provides robust evidence of the statistical significance of manager agreement on the efficacy of digital construction in mega-construction information and complexity management. Overall, Table 7.6 findings suggest Nigerian project managers widely agree that digital construction adoption enhances their information management competence, thus enabling effective mega-construction complexity management.

These empirical findings indicate that Nigerian mega-construction project managers perceive digital construction to be highly effective in enhancing their information management competence and addressing intricacies. Rigorous statistical analysis leading to null hypothesis rejection further strengthens the validity and reliability of these assertions, lending credibility to research outcomes and conclusions.

Table 7.6 Inferential statistic results from H2d

H2d	Information management (construct)	Mean (1 < y < 7)	S. D	Calculated-T ($y \geq 1.6558$ one-tailed critical *t*)	$p < 0.05$	Remark (H_0: $\mu_1 \leq 4$)
H2.1d	Support information gathering	5.84	1.051	20.839	0.001	Accepted
H2.2d	Provide a common data environment	5.77	1.038	20.290	0.001	Accepted
H2.3d	Support real-time information gathering	5.74	1.149	18.031	0.001	Accepted
H2.4d	Promote information storage	5.89	1.043	21.486	0.001	Accepted
H2.5d	Enhance information access	6.10	1.030	24.195	0.001	Accepted
H2.6d	Provides numerous information source	5.63	1.149	16.858	0.001	Accepted

H2e: Decision-making

Hypothesis 2e$_0$: Digital construction does not support managers to make decisions that curtail complexity during mega infrastructure construction

The one-sample t-test examined the H2e sub-hypotheses on whether digital construction enables responsive decision making for project managers in Nigerian mega-construction. As shown in Table 7.7, these findings are significant. In H2.1e, managers agreed that digital construction supports the analysis of decisions from multiple viewpoints. The calculated t-value (18.470) exceeded the critical value, and the p-value was below 0.05, leading to null hypothesis rejection. Digital construction facilitates collaborative decision-making with 95% confidence. This aligns with research that emphasises collaborative platforms and technologies that enable collaborative construction decision-making (Kapogiannis, 2019).

Similarly, for H2.2e and H2.3e, the calculated t-values exceeded the critical values, and the results were statistically significant at $p < 0.05$. The observed mean values exceeded the expected mean value of 4. The results demonstrate that managers agree that adopting digital construction enables gathering relevant information for decision framing, despite unforeseen circumstances, and identifying alternative decisions to manage project tempo. Managers unanimously agreed that digital construction allows pertinent information gathering when confronted with unforeseen circumstances and enables the identification of alternative decisions to effectively manage project tempos. Prior research has also highlighted the benefits of digital construction for gathering information (Sacks et al., 2020). This study empirically establishes that digital construction allows managers to gather information, ensuring efficient tempo management and decision-making despite the dynamic complexity.

Additionally, managers unanimously agree that digital construction enables gathering of multi-source on-site information and transmitting real-time decisions during mega-construction. Statistical test results for H2.4e, H2.5e, H2.6e, and H2.7e supported null hypothesis rejection, indicating consensus on the efficacy of digital construction in information gathering, real-time decision transmission, implementation, and monitoring in mega-construction. This aligns with studies that emphasise digital tools and technologies for real-time information sharing and decision-making in project management (Sepasgozar et al., 2022). The t-test provided robust evidence to reject the null hypotheses at $p < 0.05$, supporting digital construction enhancement of decision-making capabilities and complexity management for Nigerian mega-construction project managers.

In conclusion, the t-test findings for the H2e sub-hypotheses provide substantial evidence of the benefits of digital construction in enabling responsive decision making for mega-construction project managers in Nigeria. The analysis in Table 7.7 demonstrates high-confidence null hypothesis rejection, indicating that managers perceive digital construction as valuable for multi-perspective analysis, information gathering despite uncertainties, identifying alternative decisions, and real-time transmission. Overall, the results empirically establish the positive impact of digital construction on decision-making capabilities in the Nigerian mega-construction context.

Table 7.7 Inferential statistical results for H2e

H2e	Decision-making (constructs)	Mean ($1 < y < 7$)	S. D	Calculated-T ($y \geq 1.6558$ one-tailed critical t)	$p < 0.05$	Remark ($H_0: \mu_1 \leq 4$)
H2.1e	Collaborative decision making	5.11	1.096	18.470	0.001	Accepted
H2.2e	Information gathering for decision-framing	5.74	1.361	15.161	0.001	Accepted
H2.3e	Alternative decision making	5.28	1.172	23.760	0.001	Accepted
H2.4e	Holistic decision-making	5.53	1.156	15.735	0.001	Accepted
H2.5e	Decision transmission	5.22	1.299	21.210	0.001	Accepted
H2.6e	Concurrent decision implementation	5.88	0.996	22.401	0.001	Accepted
H2.7e	Decision monitoring	5.69	1.231	16.277	0.001	Accepted

H2f: Problem-solving

Hypothesis 2f$_0$: Digital Construction does not enable project managers to solve complex challenges during infrastructure construction

The average score for the " perceived potential problem " construct (H2.1f) was 5.55, with a standard deviation of 1.279. The calculated t-value of 14.356 indicates a significant difference between the observed and expected means. A p-value of 0.001 was below the significance level of 0.05. Consequently, the null hypothesis was rejected, providing compelling evidence that participants agreed that digital construction enables the perception of potential problems from specification changes during Nigerian mega-construction. Similarly, the mean H2.2 f score is 5.71, with a standard deviation of 1.105. The calculated t-value of 18.360 significantly surpassed the critical value, with a p-value of 0.001. This provides evidence to reject the null hypothesis, indicating that project managers are confident that digital construction supports the gathering of relevant information from multiple locations when mega-construction problems occur.

Regarding the "Enhance work sequence" construct (H2.3f), the mean score was 5.48, with a standard deviation of 1.371. The calculated t-value of 12.837 indicated a significant difference between the observed and expected means. The p-value of 0.001 was below 0.05. Consequently, the null hypothesis is rejected, indicating that managers are confident that digital construction facilitates the generation of work sequences catering to topography-stemming complexity. For

H2.4f, the average score for generating workable solutions is 5.40, with a standard deviation of 1.419. The calculated t-value of 11.695 indicates a significant difference between the means. A p-value of 0.001 led to null hypothesis rejection, providing strong evidence that digital construction enables solutions to manage task difficulty uncertainty effects.

Similarly, for the "Implement viable solution" construct (H2.5f), the mean score was 5.48, with a standard deviation of 1.561. The calculated t-value of 11.221 exceeds the critical value, indicating a significant difference between the observed and expected means. The p-value of 0.001 led to null hypothesis rejection; positing managers agree that digital construction enables the implementation of viable solutions curtailing untried method uncertainty impacts. Finally, for H2.6f, the mean score surpassed the hypothesised mean of 4, and inferential statistics yielded a t-value of 14.078, significantly exceeding the critical value. The p-value of 0.001 provided evidence to reject the null hypothesis, robustly supporting the idea that digital construction assists in evaluating selected solution impacts for managing scope uncertainty.

The findings in Table 7.8 align with research advocating digital construction implementation to enhance construction problem-solving (Sacks et al., 2020; Zhou et al., 2017). These studies emphasise the effectiveness of digital tools and technologies' in facilitating problem-solving during construction projects. The current study's findings further reinforce this notion by demonstrating the effectiveness of digital construction in improving Nigerian mega-construction problem solving. In conclusion, Table 7.8 results demonstrate managers perceive digital construction as valuable for perceiving problems, gathering information, enhancing sequences, generating solutions, implementing solutions, and evaluating their impacts. The null hypothesis rejection for all constructs indicated that digital construction positively influences Nigerian project managers' problem-solving competence.

Table 7.8 Inferential statistical results for H2f

H2f	Decision-making (constructs)	Mean ($1 < y < 7$)	S. D	Calculated-T ($y \geq 1.6558$ one-tailed critical t)	$p < 0.05$	Remark (H_0: $\mu_1 \leq 4$)
H2.1f	Perceive potential problems	5.55	1.279	14.356	0.001	Accepted
H2.2f	Support information gathering	5.71	1.105	18.360	0.001	Accepted
H2.3f	Enhance work sequence	5.48	1.371	12.837	0.001	Accepted
H2.4f	Generate workable solutions	5.40	1.419	11.695	0.001	Accepted
H2.5f	Implement viable solution	5.48	1.561	11.221	0.001	Accepted
H2.6f	Evaluate solutions impact	5.65	1.394	14.078	0.001	Accepted

7.4.3 Inferential Statistics for Hypothesis Three

Hypothesis 3 investigated the relationship between digital construction and project managers' competence in managing the complexity of construction projects. To examine this relationship, Pearson's correlation coefficient was used to assess the strength and direction of the association between variables. Additionally, a multiple regression analysis was conducted to explore how digital construction impacts project managers' competence, considering the various sub-hypotheses that suggest a positive influence of digital construction on their ability to manage complexity.

By examining the relationship between Hypotheses 1, 2, and 3, we can obtain a comprehensive understanding of how digital construction enhances project managers' competence in managing complexity. The use of multiple regression analysis enables an assessment of the overall fit of the regression model, providing further insights into the relationship between digital construction and project managers' competence. As discussed earlier, the results for each competence dimension are presented in subsequent sections. This analysis offers valuable insights into the specific aspects of project managers' competence impacted by digital construction in mega-construction projects.

Hypothesis 3a: Communication

Hypothesis 3.1, as presented in Table 7.9, indicates a significant relationship between these variables. The Pearson correlation coefficient (r) for this relationship is 0.483, suggesting a moderate positive correlation. This implies a statistically significant and positive linear relationship between independent and dependent variables. The coefficient of determination (r^2) was 0.233, indicating that approximately 23.3% of the variance in project managers' planning influence can be explained by the communication mechanism provided to interact with multiple project participants concurrently.

The adjusted r^2, which considers the number of predictors in the model, was 0.228. This indicates that approximately 22.8% of the variance in project managers' planning influence is explained when considering the influence of the communication mechanism after adjusting for other variables in the model. The t-value was 6.502, and its associated p-value was less than 0.001, further supporting the hypothesis. This indicates that the independent variable, "Provide a suitable communication mechanism to interact with numerous project participants concurrently," significantly affects the dependent variable, "Digital construction influence on project managers' communication." This statistically significant relationship highlights that adopting digital construction improves efficient communication channels to enhance project planning outcomes in the digital construction environment.

In evaluating H3.2a, the findings revealed a positive correlation ($r = 0.209$) between variables, implying a limited association. Approximately 4.4% of the variance in the dependent variable was ascribed to the independent variable (r^2). Although the t-value (2.525) demonstrated statistical significance, the p-value (0.13) fell short of the predetermined threshold (0.05), signifying insufficient evidence to reject the null hypothesis. Additional in-depth analysis is imperative to comprehend this correlation better when managing the complexity of mega-construction projects in Nigeria.

Similarly, H3.4a revealed a weak positive relationship (correlation coefficient = 0.212), suggesting that an enhanced reporting system might contribute to a greater influence of digital construction on planning. However, this relationship was not statistically significant ($p = 0.12$), implying the possibility of chance results. The adjusted R-squared value (0.038) indicates that the reporting system explains only a meagre portion (3.8%) of the variation in digital construction's influence on planning. Consequently, additional research is necessary to comprehend the intricate factors influencing project managers' planning in Nigerian mega-constructions.

The results presented in Table 7.9 indicate significant positive correlations between H3.3a, H3.5a, and H3.6a and project managers' planning competence in digital construction projects. Onsite communication had a moderate correlation (*r* = 0.422), explaining approximately 17.8% of the variation in planning capability. The improved feedback systems also demonstrated a moderate correlation (*r* = 0.467), accounting for approximately 21.2% of the variation. Timely instruction dissemination showed a positive relationship (*r* = 0.387), influencing approximately 15% of planning effectiveness. Despite the significant results, other factors, such as managers' experience and project complexity, also contribute and require further examination. These findings underscore the importance of digital construction in enhancing effective communication and providing timely instruction in managing complex construction projects, suggesting the need to provide more robust systems to aid project managers during mega-construction development.

Hypothesis 3a was examined using multiple regression analysis to investigate the relationship between the sub-hypotheses and the main factor that determines the effectiveness of digital construction in enhancing project managers' communication competence. The analysis revealed a significant positive correlation (*r* = 0.619) between the combined independent and dependent variables, indicating a robust linear relationship. The coefficient of determination (r^2) showed that the independent variables in the model explained 38.3% of the variance in the dependent variables. The F-statistic (13.848) indicates a statistically significant overall fit, suggesting that the independent variables collectively predicted the dependent variable. This was further supported by the low p-value (0.001), providing robust evidence to affirm a significant relationship between the independent and dependent variables.

The analysis supports sub-hypothesis 3a, indicating a significant relationship between independent and dependent variables. Specific independent variables (3.1a, 3.3a, 3.5a, and 3.6a) significantly impacted project managers' planning when digital construction was implemented, whereas 3.2a and 3.4a may not have a substantial influence. However, it is essential to note that approximately 64.5% of the variance in the dependent variable remained unexplained by the current model, suggesting the presence of other influential variables not considered in the analysis. Future research should explore additional predictors to enhance the understanding of this relationship further.

Table 7.9 Regression Results for H3a

		Regression Output						
		Model Summary			ANOVA		Coefficients	
H3a	Independent variable	R	R^2	Adjusted R^2	*F*	Sig	*t*	Sig
3.1a	Provide a suitable communication mechanism to interact with numerous project participants concurrently	0.483	0.233	0.228	42.271	<0.001	6.502	<0.001
3.2a	Proffer an appropriate communication system to actively interact with participants on multiple project sites.	0.209	0.044	0.037	6.377	0.13	2.525	0.13
3.3a	Ensure a communication channel that fosters timely response on-site during construction.	0.422	0.178	0.172	30.050	<0.001	5.482	<0.001
3.4a	Supports managers with a reporting system to transmit project specification changes effortlessly.	0.212	0.045	0.038	6.514	0.12	2.552	0.12
3.5a	Provides managers with a robust feedback system to transmit accurate instructions from the numerous project drawings	0.467	0.218	0.212	38.705	<0.001	6.221	<0.001
3.6a	Enable managers to distribute timely instructions to disperse project teams	0.387	0.150	0.144	24.535	<0.001	4.953	<0.001
	Multiple Regression Output	**0.619**	**0.383**	**0.355**	**13.848**	**<0.001**		

Hypothesis 3b: Planning

The regression analysis in Table 7.10 investigated the relationships between the independent and dependent variables, representing the influence of digital construction on project managers' planning. The overall regression model yielded an r-squared value of 0.393, indicating that approximately 39.3% of the variance in the dependent variable could be explained by the independent variables considered collectively. The coefficient of determination (r^2) indicates the proportion of variance in project manager competence that the independent variables can explain.

For each dimension of planning competence (H3.1b, H3.2b, H3.3b, H3.4b, H3.5b, H3.6b), the r^2 values range from 0.120 to 0.242, suggesting that the independent variables account for 12.0% to 24.2% of the variance in project managers' competence. The adjusted r^2 values, considering the number of predictors, ranged from 0.114 to 0.237.

The F-statistic evaluates the overall significance of the regression model, ranging from 18.964 to 44.472, all of which are statistically significant ($p < 0.001$). These results indicate that the regression models have a significant overall fit, suggesting that the independent variables collectively contribute to explaining project managers' planning competence in complexity management. The t-test was used to assess the individual significance of each independent variable. For each competence dimension, the t-values ranged from 4.355 to 6.669, all statistically significant ($p < 0.001$). These findings indicate that each independent variable significantly and positively affects project managers' competence in managing complexity.

Individually, each sub-hypothesis demonstrated a significant relationship with the dependent variable. H3.1b, exploring different planning approaches to manage sequence rigidity during construction, exhibited a correlation coefficient (r) of 0.353 and a significant F-value of 19.725 ($p < 0.001$). H3.2b, breaking down the project scope into more workable components, yielded a higher correlation coefficient (r) of 0.492 with an F-value of 44.472 ($p < 0.001$). H3.3b, ensuring easy scheduling of workers irrespective of the overall size of the project site, displayed a correlation coefficient (r) of 0.347 with an F-value of 19.056 ($p < 0.001$).

Additionally, H3.4b, which accurately forecasted the resources required during construction by estimating the budget, showed a correlation coefficient (r) of 0.397, with an F-value of 25.932 ($p < 0.001$). H3.5b, implementing measures to achieve defined quality objectives when using unfamiliar construction methods, exhibited a correlation coefficient (r) of 0.346 with an F-value of 18.964 ($p < 0.001$). Finally, H3.6b, which provides a platform to monitor the project's vast supply chain, displayed a correlation coefficient (r) of 0.410, with an F-value of 28.032 ($p < 0.001$). These results indicate that each independent variable significantly impacts the influence of digital construction on project managers' planning.

Multiple regression analysis demonstrates that the independent variables related to different dimensions of competence significantly contribute to explaining project managers' overall planning competence in managing complexity, as evidenced by the overall r^2 value of 0.393. The results in Table 7.10 indicate that the independent variables included in the model explained 39.3% of the variance in project managers' competence. The analysis provides strong empirical support for the positive relationship between digital construction and project managers' planning competence in managing complexity within construction projects.

Table 7.10 Inferential Statistics for H3b

Regression Output								
		Model Summary			**ANOVA**		**Coefficients**	
H3b	**Independent Variable**	**R**	**R²**	**Adjusted R²**	***F***	**Sig**	***t***	**Sig**
H3.1b	Explore different planning approaches to manage sequence rigidity during construction.	0.353	0.124	0.118	19.725	<0.001	4.441	<0.001
H3.2b	Breakdown the project scope into more workable components	0.492	0.242	0.237	44.472	<0.001	6.669	<0.001
H3.3b	Easily schedule workers irrespective of the project site's overall size	0.347	0.121	0.114	19.0.56	<0.001	4.365	<0.001
H3.4b	Forecast resources required during construction by accurately estimating the budget	0.397	0.157	0.151	25.932	<0.001	5.092	<0.001
H3.5b	Implement measures to achieve defined quality objectives when using unfamiliar construction methods.	0.346	0.120	0.114	18.964	<0.001	4.355	<0.001
H3.6b	Provides a platform to monitor the project's vast supply chain	0.410	0.168	0.162	28.032	<0.001	5.295	<0.001
	Multiple Regression Output	**0.627**	**0.393**	**0.351**	**9.429**	**<0.001**		

Hypothesis 3c: Coordination

H3c examined the impact of various construction management practices on project manager coordination within a digital construction environment using multiple regression analysis. The results revealed significant findings for several sub-hypotheses, indicating positive correlations between digital construction and constructs related to coordinating site activities, integrating construction activities, scheduling equipment, and organising on-site subcontractors. However, the two sub-hypotheses do not yield statistically significant results (H3.2c and H3.6c).

Sub-hypothesis H3.1c demonstrated a notable correlation with the dependent variable, with approximately 17.2% of the variance attributed to this variable. A statistically significant influence at the 99.9% confidence level indicates a substantial impact on project coordination. In contrast, H3.2c showed a weaker positive correlation but remained statistically significant at the 95% confidence level, suggesting a moderate impact of comprehensive work breakdown structure design on project coordination.

Sub-hypothesis H3.3c stood out as a significant factor, explaining 18.3% of the variance in the dependent variable. It displayed a strong positive correlation and potent influence when construction activities were integrated. H3.4c also had a discernible effect, accounting for 15% of the variance and showing a strong positive correlation with scheduling equipment. H3.5c explained 7.1% of the variance and had a statistically significant impact, confirming its importance in the coordination process, albeit with a lower positive correlation. The correlation with virtual teams in H3.6c was the weakest among the variables but remained statistically significant at the 95% confidence level.

The multiple regression analysis considering all the independent variables demonstrated a significant relationship between digital construction and project manager coordination (Table 7.11). The model accounts for 31.1% of the variance in the dependent variable, indicating a moderately strong relationship. The overall model was statistically significant, suggesting it effectively predicted the dependent variable. These findings support the notion that digital construction influences project managers' coordination efforts in mega-construction projects, specifically in coordinating site activities, integrating construction activities, scheduling equipment, and organising on-site subcontractors. This contributes to understanding how digital construction enhances project managers' coordination capabilities and informs the implementation of digital tools and technologies in construction project management processes.

Table 7.11 Inferential Analysis Results for H3c

Regression Output								
		Model Summary			ANOVA		Coefficients	
H3c	Independent Variable	R	R^2	Adjusted R^2	*F*	Sig	*t*	Sig
3.1c	Ensure numerous site activities forming a workflow are efficiently coordinated when relying on other project's input	0.415	0.172	0.166	28.925	<0.001	5.378	<0.001
3.2c	Enable comprehensive work breakdown structure design to cope with the enormous project scope	0.172	0.030	0.023	4.245	0.041	2.060	0.041
3.3c	Integrate construction activities to complement available resources on large construction sites	0.428	0.183	0.177	31.189	<0.001	5.585	<0.001
3.4c	Schedule equipment on large construction sites to ensure optimal usage	0.387	0.150	0.143	24.443	<0.001	4.944	<0.001
3.5c	Organise numerous subcontractors on-site when having to rely on other projects	0.267	0.071	0.064	10.639	0.001	3.262	0.001
3.6c	Correspond with virtual teams supporting the project from multiple locations	0.181	0.033	0.026	4.710	0.32	2.170	0.032
	Multiple Regression Output	**0.557**	**0.311**	**0.268**	**7.269**	**<0.001**		

Hypothesis 3d: Information Management

The regression analysis for H3d examined the relationship between digital construction and project managers' information management competence. The results from the regression output revealed significant findings for several sub-hypotheses (3.1d, 3.2d, 3.3d, and 3.5d). These sub-hypotheses demonstrate statistically significant positive correlations between digital construction and constructs associated with collecting project information, providing a shared data environment, gathering real-time information, and making project information accessible from multiple site locations. However, sub-hypotheses 3.4d and 3.6d do not yield statistically significant results.

Individually, sub-hypothesis 3.1d exhibited a moderately positive correlation (r=0.297) and accounted for 8.8% of the variance in the dependent variable. An F-value of 13.430 and a p-value of less than 0.001 indicated a statistically significant influence at a 99.9% confidence level. Sub-hypothesis 3.2d displayed a stronger positive correlation (*r*=0.364) and explained 13.2% of the variance in the dependent variable. This also yielded a statistically significant result at the 99.9% confidence level ($p<0.001$), suggesting a substantial impact.

For sub-hypothesis 3.3d, the results showed a strong positive correlation (*r*=0.385) and explained 14.8% of the variance in the dependent variable. It was statistically significant at the 99.9% confidence level ($p<0.001$), indicating a significant influence on project manager coordination. In contrast, sub-hypothesis 3.4d did not exhibit a statistically significant impact despite a weak positive correlation (*r*=0.146) explaining 2.1% of the variance. Similarly, sub-hypothesis 3.6d showed no statistically significant relationship with a negligible positive correlation (r=0.060), explaining only 0.4% of the variance.

The multiple regression analysis, incorporating all the independent variables, demonstrated a significant relationship between digital construction and the information management of project managers ($r^2 = 0.294$). The multiple correlation coefficient (r) was 0.543, indicating a moderately positive relationship between the combined independent and dependent variables. The F-statistic of 9.315 was statistically significant at the 99.9% confidence level ($p<0.001$), signifying that the regression model effectively predicted the dependent variable.

The findings highlighted in Table 7.12 suggest that digital construction significantly influences project managers' information management competence, particularly in areas related to collecting project information, providing a shared data environment, gathering real-time information, and making project information accessible from multiple site locations. The non-significant results for sub-hypotheses 3.4d and 3.6d imply that these specific constructs may have a lesser impact on project managers' information management competence within the digital construction context. These results contribute to our understanding of how digital construction affects project managers' information management capabilities and can inform the implementation of digital tools and technologies in construction project management processes.

Table 7.12 Regression Analysis for H3.2d – Information Management

		Regression Output						
		Model Summary			ANOVA		Coefficients	
H3d	**Independent variables**	**R**	**R^2**	**Adjusted R^2**	***F***	**Sig**	***t***	**Sig**
3.1d	Collect project information to estimate time and budget accurately.	0.297	0.088	0.082	13.430	<0.001	3.665	<0.001
3.2d	Provides common data environment as a holistic medium to distribute project specification changes to subcontractors concurrently	0.364	0.132	0.126	21.211	<0.001	4.606	<0.001
3.3d	Gather real-time information on construction challenges from numerous project teams on-site	0.385	0.148	0.142	24.148	<0.001	4.914	<0.001
3.4d	Accurately store project information changes over a more extended project duration	0.146	0.021	0.014	3.027	0.084	1.740	0.084
3.5d	Make project information accessible from multiple site locations to resolve any request for information (RFIs)	0.265	0.07	0.063	10.481	0.002	3.238	0.002
3.6d	Ensures redundant information is prevented from the numerous information source	0.060	0.004	-0.004	0.502	0.480	-0.71	0.480
	Multiple Regression Output	**0.543**	**0.294**	**0.263**	**9.315**	**<0.001**		

Hypothesis 3e: Decision-making

The purpose of the statistical analysis conducted for H3e is to examine the influence of different decision-making constructs on the role of digital construction in project managers' decision-making processes. The relationship was assessed using individual linear regression followed by multiple regression. Among the tested sub-hypotheses, H3.1e, which focused on enabling managers to analyse decisions from the viewpoint of project participants, demonstrated minimal impact and an insignificant coefficient (r=0.057, p=0.498), indicating its negligible influence on the impact of digital construction on project managers' decision-making. In contrast, H3.2e exhibited a moderate and significant relationship (r=0.397, P <0.001), suggesting a considerable impact. This indicates that the ability of digital construction to enhance project managers' collection of relevant information during unpredictable situations significantly contributes to effective decision-making in digital construction environments.

The constructs "Decide based on the available information gathered from multiple locations on-site" (H3.4e), "Implement decisions on multiple locations to curtail the effects of uncertainty" (H3.6e), and "Monitor the implication of the decisions taking into account the revised project baseline" (H3.7e) demonstrated statistically significant positive relationships, indicating their crucial roles in shaping project managers' decision-making in digital construction projects. However, H3.5e displays a weak and non-significant relationship (r=0.061, p=0.474), suggesting its limited impact on project managers' decision-making in the context of digital construction.

The multiple regression analysis in Table 7.13 reveals an r-value of 0.470, an r^2 value of 0.221, and an Adjusted r^2 value of 0.180, indicating that these constructs can explain approximately 22.1% of the variance in project managers' decision-making efficacy. This model was statistically significant (F = 5.376, p < 0.001). Among the tested sub-hypotheses, three constructs, namely H3.2e, H3.4e, and H3.6e, significantly influenced project managers' decision-making in digital construction. However, the remaining constructs showed weak and non-significant relationships, suggesting a need for further investigation and analysis.

Table 7.13 Statistical Results for H3e

Regression Output								
		Model Summary			**ANOVA**		**Coefficients**	
H3e	**Independent variables**	**R**	**R²**	**Adjusted R²**	***F***	**Sig**	***t***	**Sig**
3.1e	Enable managers to analyse decisions from the viewpoint of the numerous project participants	0.057	0.003	-0.004	0.461	0.498	0.679	0.498
3.2e	Gather relevant information that supports decision-framing in the face of unforeseen circumstances	0.397	0.157	0.151	25.930	<0.001	5.092	<0.001
3.3e	Identify alternative decisions that could be adopted to manage project tempo	0.034	0.001	-0.006	0.161	0.689	-0.401	0.689
3.4e	Decide based on the available information gathered from multiple locations on-site	0.263	0.069	0.062	10.300	0.002	3.209	0.002

3.5e	Transmit decisions clearly to the entire project participants in real-time	0.061	0.004	-.003	0.515	0.474	0.718	0.474
3.6e	Implement decisions in multiple locations to curtail the effects of uncertainty	0.317	0.100	0.094	15.524	<0.001	3.940	<0.001
3.7e	Monitor the implication of the decisions taking in cognisance of the revised project baseline	0.181	0.033	0.026	43742	0.031	2.173	0.031
	Multiple Regression Output	**0.470**	**0.221**	**0.180**	**5.376**	**<0.001**		

Hypothesis 3f: Problem-solving

Multiple regression analyses were performed to assess the impact of digital construction on project managers' problem-solving ability. Each independent variable represents a different aspect of the problem-solving process, and the analysis aimed to determine the nature and magnitude of their respective influences. The results in Table 7.14 revealed significant relationships between the independent and dependent variables. For H3.1f, a marginal yet significant positive relationship was observed (*r*=0.251, p=0.003). This suggests that an improved ability to identify potential issues related to project specification changes contributes to more effective problem-solving in digital construction. Similarly, Hypothesis 3.2f showed a weak but significant relationship with the dependent variable (*r*=0.184, p=0.029), indicating the capacity of digital construction to gather relevant information from different site locations, significantly influencing project managers' decision-making processes, particularly when faced with challenges.

In the case of H3.3f, a statistically significant correlation was found (*r*=0.279, p<0.001), suggesting that analysing work sequences for potential adaptations can provide viable solutions to challenges posed by site topography, thereby enhancing problem-solving in digital construction. However, H3.4f demonstrated only a marginal and non-significant relationship with the dependent variable (*r*=0.121, p=0.153), suggesting that generating potential solutions for task difficulty may not affect problem-solving when digital construction is employed.

H3.5f exhibited a weak but significant relationship (*r*=0.205, p=0.015), indicating that the digital construction's ability to facilitate the implementation of feasible solutions can mitigate the adverse effects of uncertainty from using untested construction methods and significantly influence decision-making processes. Finally, H3.6f displayed a moderate and highly significant correlation with the dependent variable (*r*=0.353, p<0.001), highlighting the importance of effectively evaluating the impacts of solutions in managing scope uncertainty and improving problem-solving in digital construction.

The multiple regression output for H3f revealed that the constructed model accounted for 48.5% of the total variation in the dependent variable (*r*=0.485). The predictors collectively explained approximately 21% of the variance (r^2=0.210) and, after adjusting for the number of predictors, accounted for approximately 17.5% of the variance (Adjusted r^2=0.175). The F-statistic (F=5.932) was statistically significant at p<0.001, indicating the overall significance of the regression model. These findings provide robust evidence for the connection between digital construction and project managers' problem-solving abilities. The model's statistical significance suggests that the observed relationships are not due to chance, thus enhancing confidence in its predictive power. This underscores the importance of digital tools and methodologies in shaping effective problem-solving strategies in project management in the construction industry.

Table 7.14 Regression Output for H3f

Regression Output								
		Model Summary			**ANOVA**		**Coefficients**	
H3f	**Independent variables**	**R**	**R^2**	**Adjusted R^2**	***F***	**Sig**	***t***	**Sig**
3.1f	Perceive potential problems that may occur from project specification changes	0.251	0.063	0.056	9.329	0.003	3.054	0.003
3.2f	Gather relevant information from multiple locations when a problem occurs on-site.	0.184	0.034	0.027	4.867	0.029	2.206	0.029
3.3f	Evaluate rigid work sequence to determine viable solutions to challenges from the site topography.	0.279	0.078	0.071	11.722	<0.001	3.424	<0.001
3.4f	Generate workable solutions to manage uncertainty effects from task difficulty.	0.121	0.015	0.008	2.063	0.153	1.436	0.153
3.5f	Implement the most viable solution to curtail the negative impact of uncertainty stemming from untried construction methods.	0.205	0.042	0.035	6.088	0.015	2.467	0.015

3.6f	Evaluate the positive impact of the selected solutions in managing scope uncertainty.	0.353	0.124	0.118	19.737	<0.001	4.443	<0.001
	Multiple Regression Output	**0.485**	**0.210**	**0.175**	**5.932**	**<0.001**		

Summary

This chapter presents the results of inferential analyses investigating the impact of digital construction on project manager competence in managing complexity during Nigerian mega-construction projects. One-sample t-tests assessed project managers’ agreement on the efficacy of digital construction in enhancing competence. The findings indicated a general agreement on competence improvements, especially coordination. These results refuted null hypothesis 1, confirming the conceptual framework's Relationship A outlining the digital construction's competence influence. Additionally, Hypothesis 2, which explored the associations between strategies, competence, and complexity management, is supported. T-tests revealed that digital construction enhanced competence in managing Nigerian mega-construction complexities. Finally, Hypothesis 3 examined the correlation between digital construction and complexity management competence in megaprojects, determining the extent of competence improvement of digital construction for complexity management. Although encouraging, further investigation is required to identify how digital construction enhances decision-making and problem-solving competence in complexity management in the Nigerian mega-construction context. The next chapter will thoroughly discuss these quantitative analysis results, including the implications, interpretations, and significance relative to the research objectives and literature.

Chapter 8 Discussion of Results

This chapter presents a detailed examination of the findings derived from the hypothesis testing conducted in Chapter Seven, primarily focusing on providing robust empirical support for the critical relationships identified within the conceptual framework. Through rigorous evaluation of these results, a cohesive narrative emerges that substantiates the established theoretical constructs. The findings obtained play a crucial role in fortifying the conceptual foundations of the study and relating to achieving Objectives 4 and 5. Specifically, the results shed light on the intricate dynamics governing mega-construction projects, particularly the significant influence of digital construction on the competence of project managers to navigate complexity effectively. Moreover, this chapter assesses the practical feasibility of the conceptual framework in addressing real-world challenges and limitations of mega-construction. In doing so, it transitions to address Objective 6 by evaluating the alignment of the proposed framework with the actual complexities and constraints in mega-construction projects.

Objective four: Examine the potential of digital construction to enhance project management competence in addressing structural complexity during mega-infrastructure construction.

Objective five: Determine the impact of digital construction on project managers' competence in managing the effects of dynamic complexity during mega-infrastructure construction.

Objective six: Develop a conceptual framework for complexity management in the context of mega infrastructure construction, considering the interplay between project strategy, project manager competence, and project complexity, focusing on the role of digital construction.

8.1 Overview

Managing complexity during infrastructure construction remains a significant concern as it often harms project managers. Delays and cost overruns in mega-infrastructure development are frequently attributed to project managers' struggles to manage complex trajectories (Ma and Fu, 2020). Despite the plethora of studies and recommendations on this issue, a question arises as to why the situation remains unchanged. Considering this, the current study posits that project managers’ competence can be significantly enhanced to tackle complexity trajectories by embracing digital construction, as demonstrated in Chapter 6. However, the extent to which this adoption enhances the competence of project managers remains to be determined.

This study contributes to the existing body of knowledge by evaluating the impact of digital construction on project management competence in managing complexity during infrastructure construction in Nigeria. The following sections delve into the results obtained from the data analysis in Chapter Seven, providing support for the research findings and shedding further light on the subject.

8.1.1 Communication

$H3a_0$: There is no relationship between digital construction's influence on project managers' communication competence and digital construction augmenting project managers to manage communication complexity during infrastructure construction

The sub-hypothesis that holistically answers H3a is presented in Table 8.2.

Table 8.1 Sub-Hypotheses for H3a

H3a	Construct	Hypothesis Support
3.1a	Provide a suitable communication mechanism to interact with numerous project participants concurrently	**Supported**
3.2a	Proffer an appropriate communication system to interact with participants on multiple project sites actively.	**Not Supported**
3.3a	Ensure a communication channel that fosters timely response onsite during construction.	**Supported**
3.4a	Supports managers with a reporting system to transmit project specification changes effortlessly.	**Not Supported**
3.5a	Provides managers with a robust feedback system to transmit accurate instructions from the numerous project drawings	**Supported**
3.6a	Enable managers to distribute timely instructions to disperse project teams	**Supported**

Effective communication is critical for managing mega-construction projects involving complex interactions between multiple stakeholders across organisations and locations. This discussion evaluates the findings regarding the potential of digital construction to enhance project managers' communication competence in managing mega-construction complexities (H3a). Quantitative analyses assessed hypotheses on digital tools' capacity to provide optimal communication mechanisms, augment manager competence, and overcome challenges, such as information overload. The results present a complex perspective, indicating certain potential benefits of digital construction in areas such as real-time collaboration while revealing persistent gaps between theoretical promises and empirical reality. Although digital construction demonstrates the potential to impact complexity management, limitations remain regarding seamless information sharing across sites.

The quantitative results presented in Chapter 7, including correlation and regression analyses, elucidate the main sub-hypotheses centred on the potential of digital construction to provide optimal communication, augmenting project manager competence amid mega-construction complexity. Digital construction can, as Wang et al. (2013) stated, enable real-time context analysis to meet complex communication needs, as opposed to the traditional rigid weekly site meetings, generic work plans, and paper-based memos (Olaniran, 2015), which have demonstrated ineffectiveness during mega-construction because of their static nature. Specifically, the analysis illuminated the findings regarding communication mechanisms in sub-hypothesis H3.1a.

Correlation analysis supported H3.1a regarding communication mechanisms, with the highest Pearson's r coefficient detailed in Table 7.9, denoting a moderate positive correlation. This suggests that digital construction can provide substantial improvements to project managers compared with traditional communication methods. Unlike periodic meetings and generic memos, real-time digital mechanisms such as BIM, augmented reality, and RFID provide managers with dynamic and situation-specific project access, enabling faster and better-informed decisions while avoiding delays and costs of miscommunication (El-Saboni et al., 2009). As complexity exacerbates coordination challenges, digital construction empowers managers with greater visibility and understanding across an intricate web of tasks and personnel by improving critical communication mechanisms for harnessing real-time insights, orchestrating activities, and exerting leadership. The quantitative findings for H3.1a corroborate the value of digital construction in providing optimal communication to enhance project managers amid complexity. This finding also highlights Nepal et al.'s (2006) suggestion that employing effective mechanisms can improve scheduling pressure management during construction.

Beyond communication mechanisms, the analysis also revealed insights into sub-hypothesis H3.5a regarding robust feedback systems to communicate drawing changes. Traditional paper-based methods are inadequate because managers cannot feasibly coordinate specifications and transmit updates to workers in real-time across multiple locations, considering that project size is a complex element that restricts effectiveness (Gamil and Rahman, 2017). Digital tools like cloud-based BIM enable synchronised remote visualisation and dynamic control of drawing revisions. Digital systems empower managers to seamlessly integrate changes by providing rapid feedback loops rather than fragmented paper hands-offs, thus overcoming challenges related to technical drawings.

Enhanced drawing communication reduces delays, confusion, and rework (Kapogiannis and Sherratt, 2018). Adopting new technologies, such as BIM and cloud platforms, requires an upfront investment, which improves communication and mitigates the risk of misinformation that could offset these costs (Bello et al., 2021). This is particularly significant for complex mega-construction, where managers must juggle vast technical specifications, heavy workloads, and site coordination (Svalestuen et al., 2017). H3.5a provides indicators of digital construction, enabling managers to communicate technical drawing changes and instructions competently. This ensures efficient communication systems and channels that can improve information dissemination and facilitate seamless interaction, thereby enhancing the management of communication complexity.

Additionally, the findings confirm that supplementary digital tools can further augment these feedback mechanisms to improve construction communication, corroborating previous studies that reflect digital construction deployment. Matthews et al. (2015) showed that cloud-based BIM enhances precise, reliable drawing-based information transfer on site. Similarly, Zhong et al. (2017) advocated using IoT and AR to improve visibility and traceability during construction, enabling project managers to operate competently. However, certain technological limitations, such as poor design of technology interfaces, may hinder the adoption of these digital communication tools (Hua et al., 2021). These findings empirically confirm H3.5a. Consequently, the sub-hypotheses H3.3a, H3.2a, H3.5a, and H3.6a unequivocally refute the null hypotheses, establishing a confidence level of 95%.

Although cross-location coordination remains unaddressed, implementing digital construction has positively enhanced project managers' competence in disseminating on-site instructions and eliciting prompt responses (Dossick and Neff, 2011). For instance, studies have demonstrated the potential of Building Information Modelling (BIM)-enabled mobile devices to facilitate real-time discussions and problem-solving, thereby reducing traditional delays (Kania et al., 2020). With megaprojects involving heavy workloads and convoluted task interdependencies, improved on-site communication gives managers the necessary visibility to coordinate activities, adapt to evolving situations, and promptly address issues. Improved dynamic exchange among participants is essential for competent management amid complexity. These empirically validated improvements in responsiveness demonstrate the potential of digital construction to transform project management practices through superior on-site communication, consistent with sub-hypotheses H3.1a, H3.3a, H3.5a, and H3.6a.

In contrast to the findings on feedback systems, the results diverged regarding multi-site communication capacities. Despite strong theoretical proposals for digital tools, such as BIM and sensors, to improve communication across fragmented construction teams (Dossick and Neff, 2011), the regression analysis found no significant relationship between digital construction and enhanced multi-site coordination (H3.2a). This discrepancy suggests possible technology constraints, industry readiness gaps, and optimistic biases that have limited the adoption and effectiveness of tools to facilitate seamless information sharing across locations. Without reliable multi-site capabilities, managers face challenges coordinating remote teams, adapting to dynamic situations, and integrating distributed project data (Yang et al., 2015). This can result in delays, wasted resources, and mismanagement of the overall complexity. These findings reveal significant gaps between the promise and reality of digital construction capacity, enabling seamless decentralised collaboration at scale.

Similarly, the analysis revealed a lack of evidence regarding the effectiveness of digital tools in specification reporting. The findings refute claims that digital construction provides robust real-time systems, per H3.4a. This implies that, despite advancements in deploying digital tools during construction, deployment within virtual environments remains limited, as Hilfert and Konig (2016) suggested. Targeted initiatives such as training and legislation can promote adoption (Gamil, 2020). Furthermore, technological advancements such as digital twins offer optimism despite the present challenges. As financial and cultural barriers are overcome, project managers may be positioned to optimally leverage these emerging tools to profoundly improve specification coordination compared to the current constraints. However, statistical evidence does not support the effectiveness of digital construction in transforming real-time specification communication; thus, accepting the null hypothesis for $H3.4a_0$.

In summary, while positive correlations indicate promising potential, limitations highlight gaps stemming from adoption challenges. These quantitative findings corroborate the conclusions of previous studies on the potential of digital construction to transform project management amid complexity (Rimmington et al., 2015). Effective communication is critical for complexity management (Gamil, 2020). Building on these quantitative results, the findings reflect a conceptual framework outlining the role of digital construction in augmenting managers through enhanced communication mechanisms. Furthermore, the results for H3a revealed a nuanced assessment of the current state of digital construction to enhance project managers' communication competence. On the one hand, adoption limitations highlight the current discrepancies between theoretical capacity and empirical implementation. However, there is potential for improvement as the technology progresses. Critical future directions could involve investigating the potential and actual adoption discrepancies.

H3a$_1$ There is a strong positive association between digital construction influence and digital construction augmenting project managers' communication competence to manage infrastructure construction complexity

8.1.2 Planning

H3b$_0$ There is no relationship between digital construction's influence on project manager's planning competence and digital construction augmenting project managers' to effectively plan infrastructure construction to curtail complexity

Table 8.2 Findings for H3b

H3b	Construct	Hypothesis Support
H3.1b	Explore different planning approaches to manage sequence rigidity during construction.	**Supported**
H3.2b	Breakdown the project scope into more workable components	**Supported**
H3.3b	Easily schedule workers irrespective of the project site's overall size	**Supported**
H3.4b	Forecast resources required during construction by accurately estimating the budget	**Supported**
H3.5b	Implement measures to achieve defined quality objectives when using unfamiliar construction methods.	**Supported**
H3.6b	Provides a platform to monitor the project's vast supply chain	**Supported**

Ineffective planning has been associated with mega-project failure outcomes, with cost and schedule overruns affecting mega-infrastructure initiatives (Nguyen et al., 2018). However, traditional project management techniques are often inadequate for large-scale complex projects. This study evaluated the hypothesis that digital construction enables more effective planning, despite its complexity. Furthermore, the regression analysis for H3b demonstrates a statistically significant positive correlation between digital construction and planning competence. This initial finding suggests the potential of digital construction to enable project managers to improve the planning of complex, interconnected mega-projects. However, new technologies have been shown to hinder planning activities rather than assist managers if they are not properly integrated with existing workflows (Lock, 2017).

In addition, the scheduling construct showed the strongest correlation (H3.2b), indicating that innovations such as 4D BIM can help segment large projects (Kunz and Fischer, 2020). Specific techniques for addressing sequence rigidity have also demonstrated potential, as suggested by Pellerin and Perrier (2019). However, project outcomes do not reflect the potential of individual tools (Enshassi and AbuHamra, 2017). This study hypothesised and confirmed that an integrated digital construction concept using multiple tools could enhance work packaging and planning simulations to manage sequence rigidity (H3.1b and H3.2b).

Moreover, previous studies have recommended integrated digital solutions to improve construction project planning and scheduling for mega-projects. For example, Chen and Tang (2019) proposed a BIM-based management approach to enhance schedule planning during mega-construction. Their approach enabled worker scheduling, corroborating H3.3b. Similarly, Wang et al. (2013) suggested combining BIM and augmented reality headsets to facilitate resource scheduling simulations by managers because large mega-construction sites warrant numerous participants and copious resources to achieve the final product (Nguyen et al., 2018). This study accepts hypotheses H3.1b, H3.2b, and H3.3b at the 95% confidence level, implying that digital construction may enable project managers to leverage various planning techniques and simplify the scope of complex projects. This is ascribed to the ability of digital construction to simulate and visualise projected resource requirements. This modelling capability could assist in mitigating the complexity stemming from mega-construction characteristics.

Furthermore, managing the sizable scope inherent in mega-construction requires comprehensive planning that encompasses scheduling, resource allocation, and quality control, which are critical factors for successful project delivery from a practical standpoint (Gudienė et al., 2014). However, some researchers caution against engineering risks from excessive planning (Collyer et al., 2010). Proponents argue that detailed planning minimises ambiguity (Kerzner, 2017). H3b shows that digital construction provides flexible adaptability. Specifically, integrating digital tools may enable managers to be more adept at planning against uncertainty.

For instance, Woo et al. (2011) demonstrated that integrated RFID systems enable enhanced logistics of workers, materials, and machinery during complex projects, exemplifying how digital construction can enable more efficient on-site resource planning relevant to planning competence. However, the narrow extent of these quantitative findings highlights the need for additional research on realising the planning potential of digital construction. The positive correlations between digital construction and planning competence are indicative but do not necessarily demonstrate tangible improvement. As discussed earlier, the planning-execution gaps persist regardless of capabilities.

Likewise, supply chain management is pivotal for resource planning and replenishment, given the sizable scope of mega-construction projects (Vrijhoef and Koskela, 2000). Traditional approaches are often inadequate for extensive procurement and subcontracting, and the need to coordinate numerous suppliers and subcontractors (Russell and Taylor, 2019). Digital construction may improve supply chain management through increased integration and coordination. For instance, Vrijhoef (2011) proposed an information-driven system to coordinate complex construction supplier networks. These indicate digital construction's potential to assist project managers with supply chain integration for mega-projects through improved visibility, coordination, and transparency, aligning with the hypothesis (H3.6b)

Additionally, geospatial technologies combined with nD BIM and sensors could enable supply chain visualisation and planning (Irizarry et al., 2013), demonstrating how digital construction might assist supply chain coordination relevant to overall planning competence through improved visibility, coordination, and transparency. Consistent with the findings from the literature, this study supports the hypothesis that combining digital techniques could augment managers' competence in managing construction supply chain complexity (H3.6b). However, as outlined earlier, quantitative results demonstrating these potentials remain primarily theoretical. Further case studies and interviews are required to develop pragmatic implementation frameworks that translate the proposed capabilities of digital construction into tangible improvements in supply chain coordination and on-site construction operations.

This study makes an important empirical contribution by providing original evidence of a significant positive relationship between adopting digital construction and enhancing project management competence in planning mega-construction projects. The quantitative results indicate that the strategic integration of appropriate digital tools has considerable potential to transform planning practices, including work scheduling, sequencing, and supply chain coordination, particularly when confronted with large scales and complexity. These findings correspond with suggestions from the proposed conceptual framework that digital construction supports project managers in planning complex construction sites. Additionally, the findings provide valuable insights for practitioners to optimise project management processes in the construction industry. Considering these findings, it is evident that adopting digital construction can enhance planning practices and offer a transformative avenue for project managers to navigate the challenges inherent in complex mega-construction projects.

H3b$_1$ There is a positive relationship between digital construction influence on project manager's planning competence and digital construction augmenting project managers to manage infrastructure construction complexity

8.1.3 Coordination

H3c$_0$ There is no relationship between digital construction's influence on project manager's coordination competence and digital construction augmenting project managers to manage coordination complexity during infrastructure construction

Table 8.3 Findings from H3c

H3c	Construct	Hypothesis Support
3.1c	Ensure numerous site activities forming a workflow are efficiently coordinated when relying on other project's input	**Supported**
3.2c	Enable comprehensive work breakdown structure design to cope with the enormous project scope	**Supported**
3.3c	Integrate construction activities to complement available resources on large construction sites	**Supported**
3.4c	Schedule equipment on large construction sites to ensure optimal usage	**Supported**
3.5c	Organise numerous subcontractors on-site when having to rely on other projects	**Supported**
3.6c	Correspond with virtual teams supporting the project from multiple locations	**Supported**

Effective coordination is widely recognised as an essential contributor to the success of construction projects. However, coordination can be problematic in complex mega-construction projects. Hypothesis 3c empirically validates whether adopting digital construction enhances Nigerian project managers' coordination competence, particularly when managing large-scale infrastructure initiatives involving intricate workflows, vast resources, and multiple specialised teams. Correlation analysis indicated that digital tools and methods could significantly augment coordination capabilities, with the most significant correlations occurring for work sequencing and resource planning activities (sub-hypotheses H3.1c and H3.3c).

Although still significant, sub-hypothesis 3.2c exhibited a weaker correlation, likely due to the unpredictability that emerges in mega-construction as complexity unfolds (Qazi et al., 2016). The findings also demonstrated that all other constructs were positively correlated and statistically significant to the influence of digital construction on project managers' coordination competence. However, some studies have found that digital tools do not necessarily enhance coordination in all cases (Sun et al., 2015). This section provides quantitative evidence of the benefits of digital construction in enhancing coordination activities.

Examining coordination activities in detail, the analysis highlighted that the benefits of digital construction were most pronounced for enhancing work sequencing (sub-hypothesis 3.1c) and resource planning (sub-hypothesis 3.3c), which constitute a major difficulty for mega-construction managers. These areas represent significant difficulties encountered in practice as managers strive to choreograph intricate workflows and distribute resources judiciously across complex initiatives. However, the unpredictability inherent in large-scale projects makes it difficult to prevent activity duplications (Nguyen et al., 2018). This explains the weaker correlation between digital construction and the deconstruction of a massive scope (H3.2c).

Nonetheless, H3c confirmed that visualising, simulating, and monitoring functionalities enabled by digital advancements could equip managers to coordinate despite their complexity. Employing tools such as BIM, UAVs, and integrated platforms has been shown to facilitate site assessments (Jiang et al., 2015), progress tracking (Kang et al., 2016), and schedule optimisation based on emerging priorities and adaptations (Sacks et al., 2020a). For Nigerian managers surveyed, adopting these technologies allows them to respond dynamically to changes and uncertainties. This improved agility demonstrates how digital construction can enhance coordination capabilities in rapidly evolving large-scale projects. The finding exhibited a moderate association for sub-hypotheses 3.1c and 3.3c, likely because these tools are more prevalent in mega-construction. Nevertheless, building expertise through training initiatives could help realise the potential capabilities of digital construction to enhance coordination competence.

Building on the coordination benefits and barriers already discussed, the findings also provide insights into managing virtual teams, an increasingly relevant topic as projects leverage global expertise (Kunz and Fischer, 2020). As hypothesised in H3.6c, digital platforms such as BIM enable project managers to connect and collaborate with remote contributors. However, a weaker correlation was found between technology adoption and virtual team coordination, where managers expressed difficulties. This aligns with previous research showing slower uptake than in other industries, often attributed to ingrained fragmentation, distrust, and integration challenges (Hilfert and König, 2016). These adoption challenges have hampered project managers from accessing potentially valuable coordination support from virtual teams. Nigerian managers similarly expressed difficulties in capitalising on digital construction to improve on-site virtual team coordination. This is consistent with the submission of persistent reluctance to virtual teamwork despite projected benefits (Sagar et al., 2022).

In addition to virtual team coordination, the data highlight implications for sequencing workflows and managing specialist teams. As hypothesised in H3.5c, Nigerian managers reported that technologies such as BIM, GPS tracking, and integrated platforms helped them effectively orchestrate workflows, access real-time progress, and optimise scheduling. This corresponds with past research showing that digital capabilities can facilitate monitoring, productivity analysis, and schedule optimisation based on emerging priorities (Jiang et al., 2015). Particular implementations, such as laser scanning combined with BIM, have demonstrated advantages for live coordination (Akula et al., 2013). These functionalities assist in planning and coordinating high-risk sequences for complex projects involving hazardous activities. Consistent with H3.5c, implementing digital construction enables Nigerian managers to improve the coordination of sequencing complex workflows and managing specialist teams, which are essential to the success of mega-construction.

In addition to workflow and team coordination, this analysis sheds light on managers' use of digital construction, particularly for equipment coordination. Equipment coordination is critical for project managers to oversee the complexity of mega-construction (Mirza and Ehsan, 2017). The analysis sheds light on managers leveraging digital tools, specifically for optimising equipment coordination, as reflected in H3.4c. This aligns with previous applications for visualising equipment locations, monitoring productivity, and integrating data to enhance coordination (Lu et al., 2007; Kim and Chi, 2020). With heavy equipment rental weighing on budgets, improved coordination enables managers to maximise their value. The respondents noted the perceived benefits of adopting digital tools for on-site equipment operation and planning.

However, an interesting pattern emerged around the team integration challenges. Managers expressed more difficulty coordinating machinery schedules and usage with the broader project group than with their individual use. As previously mentioned, this may reflect technical expertise gaps and resistance across the supply chain. Tackling these barriers could further unleash the promise of advanced technologies for optimising equipment coordination essential to the success of complex mega-construction projects.

In conclusion, this analysis examines whether digital construction enhances Nigerian project managers' coordination competence in mega-construction, focusing on work sequencing and resource planning (H3.1c—H3.6c). Advanced digital capabilities have shown potential for assessment, tracking, and schedule optimisation (Jiang et al., 2015). While barriers remain, digital construction demonstrates promise for augmenting coordination. H3c corroborates the conceptual framework that digital construction can augment project managers' coordination competence in complexity management. This study suggests a medium for refining strategies and best practices to unlock digital coordination capabilities. Targeted training and incentive programs will prove the key to realising this potential, ushering in a new era of digitally enabled coordination in complex construction projects.

$H3c_1$ There is a strong positive relationship between digital construction influence on project manager's coordination competence and digital construction augmenting project managers to manage $_0$infrastructure construction complexity

8.1.4 Information Management

$H3d_0$ There is no relationship between digital construction's influence on project manager's information management competence and digital construction augmenting project managers to effectively manage information during complex infrastructure construction

Table 8.4 Findings from H3d

H3d	Construct	Hypothesis Support
3.1d	Collect project information to estimate time and budget accurately	**Supported**
3.2d	Provides a common data environment as a holistic medium to distribute project specification changes to subcontractors concurrently	**Supported**
3.3d	Gather real-time information on construction challenges from numerous project teams on-site	**Supported**
3.4d	Accurately store project information changes over a more extended project duration	**Not Supported**
3.5d	Make project information accessible from multiple site locations to resolve any request for information (RFIs)	**Supported**
3.6d	Ensures redundant information is prevented from the numerous information source	**Not Supported**

Information management poses an essential ongoing challenge in mega-infrastructure projects, with notable effects on budget and schedule outcomes (Gamil, 2020). Despite this constraint and the suggestion that digital tool combinations could mitigate the situation (Elghaish et al., 2019), limited empirical insight exists on how integrating these tools (i.e. digital construction) shapes project managers' information management competence in this complex domain. Building on this, H3d provides quantitative evidence of how digital construction influences information management tasks for project managers in mega-infrastructure projects. These findings provide insights for academia and industry regarding the influence of digital construction on information management, which is critical for improving the performance of mega-construction projects. Specifically, sub-hypotheses H3.4d and H3.6d, which deal with archiving and dissemination functions, showed no statistically significant correlation with digital tool usage. Sub-hypotheses H3.1d — H3.3d, regarding information gathering, distribution, and access, exhibited moderately positive correlations.

The results for sub-hypothesis H3.5d show that adopting digital construction has a minor positive influence on project managers' ability to address RFI challenges in mega-infrastructure projects. Past literature characterises RFIs as typical in large, complex projects, owing to evolving information needs during construction (Jarkas, 2017). Moreover, previous studies have indicated that BIM and related technologies may enhance collaborative information exchange and decrease RFIs. (Elghaish et al., 2019). However, Nigerian managers in the current study reported only a minimal impact of digital construction on improving RFI management (H3.5d). Explanations for this outcome include deficient technical proficiency with novel tools among project stakeholders, gaps in adoption among subcontractors, time-zone differences, and ineffective response cycles.

While managers reported a minimal impact of digital construction on improving RFI processes, an unanticipated finding emerged concerning digital construction on archiving capabilities (H3.4d). The literature has proposed technological tools for improving archiving (Chen and Lu, 2019). However, the managers in this study reported a minimal impact of digital construction on archiving capabilities, an unexpected result considering its role in information management and advancements in cloud computing implementation. Issues such as frequent manager turnover and inconsistent technical expertise among subcontractors in the studied context may persist as technological capacity barriers (Gamil and Rahman, 2019). Developing protocols and training to address these human factors may be vital for realising the full benefits of digital tools in archiving project information.

In addition to archiving limitations, the distribution of project information has also emerged as an area where digital construction has not yet fully delivered the expected benefits, as seen from H3.6d. This diverges from the recent literature suggesting advances in cloud computing, and BIM have improved archiving and information accessibility in construction (Sacks et al., 2016). One potential explanation is that organisational and managerial factors may limit the realisation of these technological capabilities. For instance, a high rotation rate among project managers can preclude learning transfers and consistent archiving behaviour. Additionally, overreliance on temporary subcontractors with variable technological expertise and integration into data systems may hinder seamless information capture. Nevertheless, given the capabilities demonstrated in academic literature, additional empirical investigation is required to determine if and how digital construction can strengthen archiving and information accessibility over extended periods in mega-projects when implemented in a more integrated manner.

Regarding broader information management, other sub-hypotheses showed moderately positive relationships between digital construction and activities such as gathering, sharing, and interacting with project data. For example, H3.1d, H3.2d, and H3.3d were supported, aligning with studies showing that cloud-based BIM enhances real-time information exchange and monitoring (Matthews et al., 2015). Integrating 3D/4D BIM with other visualisation and simulation tools also improves project managers' competence in aggregating, distributing, and engaging with information (Gamil et al., 2019). The findings suggest that digital construction could support project managers in augmenting their information management competence during complex mega-construction, although barriers such as those in archiving may persist.

Notwithstanding the mixed impacts on specific activities, the results revealed a divergence between the overall positive relationship and the lack of impact on archiving and dissemination functions in sub-hypotheses H3.4d and H3.6d. Minimal digital influence also emerged for Requests for Information in H3.5d. These contradictions indicate opportunities to refine technological solutions and implementation strategies to optimise information management improvements in mega-construction projects. While aligning broadly with the promise of emerging tools, the findings elucidate where further research must continue to advance academic and practitioner's understanding of leveraging digitalisation to maximise benefits across all facets of information integration. Multiple regression analysis suggests that digital construction could influence information management competence in managing construction complexity, as proposed by the conceptual framework (Dossick and Neff, 2011; Frefer et al., 2018).

H3d₁ There is a positive relationship between digital construction's influence on project manager's information management competence and digital construction augmenting project managers to manage information during complex infrastructure construction

8.1.5 Decision-making

H3e There is no relationship between the influence of digital construction on project managers' decision-making competence and digital construction augmenting project managers to make decisions that curtail complexity during mega infrastructure construction.

Table 8.5 Findings for H3e.

H3e	Dependent Variable	Hypothesis Support
H3.1e	Enable managers to analyse decisions from the viewpoint of the numerous project participants.	**Not Supported**
H3.2e	Gather relevant information that supports decision-framing in the face of unforeseen circumstances.	**Supported**
H3.3e	Identify alternative decisions that could be adopted to manage project tempo.	**Not Supported**
H3.4e	Decide based on the available information gathered from multiple locations on-site.	**Supported**
H3.5e	Transmit decisions clearly to the entire project participants in real-time	**Not Supported**
H3.6e	Implement decisions in multiple locations to curtail the effects of uncertainty.	**Supported**
H3.7e	Monitor the implication of the decisions taken in cognisance of the revised project baseline.	**Supported**

Effective decision-making is vital for construction project managers to deliver successful outcomes within complex cultural and operational contexts (Belay et al., 2017). However, the growing complexity of mega-projects presents substantial difficulties in decision-making. As Winch (2010) indicated, the dynamic complexity arising from considerable uncertainty impedes intuitive approaches. This complexity requires sophisticated methods to improve the decision-making abilities of managers. Digital construction provides a widening array of technologies with the potential to strengthen construction decision-making, although its impacts remain underexplored, and issues surrounding adoption barriers remain (Puri and Turkan, 2020). H3e assessed the relationship between digital construction and decision-making competence for Nigerian mega-construction managers, using constructs that reflect critical steps in the classical decision-making process.

The multiple regression analysis presented in Table 8.6 served as the basis for testing sub-hypothesis H3e. Among these, H3.2e, H3.4e, and H3.6e exhibited a positive association with digital construction and yielded statistically significant results in the correlation analysis. Conversely, H3.1e, H3.3e, and H3.5e exhibited a weak association, no relationship, and were insignificant, suggesting that any potential relationship between these constructs and digital construction can be attributed to chance. H3.7e exhibits a weak correlation, with the findings being significant.

For project managers, making decisive decisions is paramount when confronted with dynamic complexity during construction, which involves selecting optimal alternatives from a range of available options (Geraldi and Adlbrecht, 2008). However, as Giezen et al. (2015) discussed in their construction project decision practice analysis, evaluating outcomes is as critical as supporting conformance with objectives. Neglecting to evaluate decisions propagates complexity and impacts the outcomes. Hence, this study hypothesised that digital construction provides mediums for real-time decision monitoring during mega-construction (H3.7e), as digital construction has shown.

Moreover, these studies demonstrate that leveraging digital construction allows project managers to effectively assess decision outcomes throughout the construction process. By integrating mobile lidar and 4D BIM, Puri and Turkan (2020) monitored activities and compared scheduling decisions. Similarly, Zhou et al. (2017) proposed using augmented reality and BIM 3D models to enable managers to monitor decisions against project baselines. Abdullahi et al. (2021) further showcased how RFID, GIS, remote sensing, and UAVs can be utilised to support evaluating decision outcomes in Nigerian infrastructure. This interconnectedness between digital construction and decision evaluation indicates the potential for real-time decision monitoring during mega-construction, as hypothesised in this study (H3.7e).

However, despite studies showing tools such as lidar and BIM support monitoring (Puri and Turkan, 2020), Nigerian managers believe that digital construction partially supports monitoring aligned with revised baselines, per the weak correlation of H3.7e. This may be due to spontaneous changes in the project baseline for mega-infrastructure construction (Ma and Fu, 2020), constraining the assessment of previous decisions as new complexities emerge (Gudienė et al., 2014). As scholars such as Sacks et al. (2020b) have discussed, advancements in machine learning and artificial intelligence may lead to automated tools for monitoring decision outcomes during infrastructure construction. The participants' tool access may have impacted their perceptions, given contrary reports. With greater digital integration, Nigerian projects may yield more positive outcomes. Although weak, H3.7e was significantly associated, thus rejecting the null hypothesis.

Similarly, for the constructs regarding enhancing decisions, project managers require mechanisms to improve decision-making and dissemination to help manage complexity (Winch, 2010), as highlighted by H3.1e, H3.3e, and H3.5e. Scholars such as Kapogiannis (2014), in examining project managers' proactive behaviours, have encouraged cultivating a collaborative culture to enhance decision-making. Additionally, researchers of integrated project delivery, such as Sacks et al. (2016), have proposed using digital tools for a more inclusive analysis, which averts bias. Emerging computer-aided tools, such as Digital Twins, which researchers Saini et al. (2022) explored, can enhance construction decision-making and are prevalent for improvement.

Such tools can also be integrated with communication platforms, allowing real-time engagement and visualisation of challenges (Sacks et al. (2020a). However, based on the statistically insignificant correlations for H3.1e, H3.3e, and H3.5e, responses from Nigerian managers suggest that digital construction does not adequately support effective on-site decisions, potentially because of the cultural hierarchies of centralise decision-making authority rather than promoting inclusive collaboration. Statistical insignificance implies that digital construction does not currently augment inclusive decision-making. Thus, H3.1e fails to reject the null hypothesis.

In contrast, H3.2e, H3.4e, and H3.6e are significantly correlated. Uncertainty drives dynamic complexity and is curtailed by incisive decisions (Belay et al., 2017). Tools like BIM, AR, and lidar can provide visual data to frame decisions when uncertainty emerges (Louis and Dunston, 2018). Cloud computing enables multi-site decision distribution (Hilfert and König, 2016). This functionality, identified in previous studies, conforms to the present results. Puri and Turkan's

(2020) lidar-BIM progress tracking framework gathers on-site data to inform decision-making when challenges arise and distribute decisions through BIM (Rimmington et al., 2015). The present study further proves that digital construction can strengthen decision-making under complex conditions. However, classical decision theory constructs showed mixed results, warranting further enquiry into aligning technology with decision science frameworks, as emphasised by Parth (2013).

Based on these results, the multiple regression analysis demonstrated an overall positive relationship between digital construction and decision-making competence for project managers facing dynamic complexity in mega-construction projects (see Table 8.6). The findings showed that specific capabilities demonstrate a connection with digital construction. However, challenges regarding inclusive, collaborative decision-making have emerged, likely stemming from adoption barriers such as subjective judgements, hierarchy, and technical inexpertise. While digital construction demonstrates the potential for informing decisions amid uncertainty, realising its effectiveness requires addressing obstacles through training focused on implementation readiness.

Considering this analysis, H3e showed that digital construction correlates positively with decision-making competence aspects such as data visualisation, confirming the relationship ***A-B-C*** of the conceptual framework. However, gaps became apparent in inclusive, collaborative decision-making processes. To address such gaps, developing strategies aligned with localised decision-making norms and hierarchies may help overcome adoption barriers and maximise the utilisation of appropriate technologies for context-sensitive decision support.

$H3e_1$ There is a positive relationship between digital construction's influence on project manager's decision-making competence and digital construction augmenting project managers to make the right decisions during complex infrastructure construction

8.1.6 Problem-solving

H3f*$_0$ *There is no relationship between digital construction's influence on project manager's problem-solving competence and digital construction augmenting project managers to solve complex problems during infrastructure construction

Table 8.6 Findings from H3f

H3f	Constructs	Hypothesis Support
H3.1f	Perceive potential problems that may occur from project specification changes.	**Supported**
H3.2f	Gather relevant information from multiple locations when a problem occurs on-site.	**Supported**
H3.3f	Evaluate rigid work sequence to determine viable solutions to challenges from the site topography.	**Supported**
H3.4f	Generate workable solutions to manage uncertainty effects from task difficulty.	**Not Supported**
H3.5f	Implement the most viable solution to curtail the negative impact of uncertainty stemming from untried construction methods.	**Supported**
H3.6f	Evaluate the positive impact of the selected solutions in managing scope uncertainty.	**Supported**

Construction projects involve extensive uncertainties, requiring project managers to resolve complex problems and address emerging challenges. However, research indicates that managers employ intuitive approaches and implicit knowledge when making important decisions, as Maylor and Turner (2017) described. Mega-construction projects involve considerable intricacies stemming from their new and variable characteristics, which can surpass individual expertise (Shenhar and Dvir, 2008). Consequently, this complexity necessitates more systematic assistance for solving construction problems. Digital construction offers an evolving array of sophisticated tools with the potential to enhance project manager capabilities. However, research on the impact of digital construction on construction problem-solving is limited. Studies indicate further examination is needed into their effects on managing construction complexity (Dossick and Neff, 2011)

H3f examined the relationship between adopting digital construction and project managers' problem-solving competence when dealing with mega-project uncertainties. This study aimed to assess whether emerging digital construction influences data-driven decision-making. This addresses a gap in understanding the potential impacts of technologies, such as BIM and augmented reality, on enhancing construction problem-solving processes. Correlation analysis shows that digital construction can provide more rigorous data-driven decision support owing to uncertainties. H3.4f exhibited statistical insignificance, negligibly associating with digital construction and evincing no apparent relationship, as shown in Table 7.14. Similarly, the findings indicated that H3.1f, H3.2f, H3.3f, and H3.5f exhibited low correlations with digital construction, whereas H3.6f displayed a moderate association.

Assessing sub-hypothesis H3.4f provides perspectives derived from Caldas and Gupta's (2017) analysis, emphasising that construction task complexity introduces uncertainty (Caldas and Gupta, 2017) that project managers frequently manage through pragmatic solutions and tacit knowledge (Maylor and Turner, 2017). However, as Salet et al. (2013) described, mega-projects can surpass the limits of experiential wisdom, leaving managers without recourse, depending solely on intuition. In response, Dossick and Neff (2011) proposed using BIM for increased collaboration and visualisation. Despite its potential benefits, automated problem-solving currently exhibits constraints (Rahimian et al., 2020). These studies confirm the realities of Nigerian construction managers that current digital tools do not sufficiently assist in solution generation amid uncertainty. This disconnection highlights the potential benefits of additional training and addressing the ingrained cultural norms.

Nevertheless, studies predicting automated problem-solving will expand commercially (Sacks et al., 2020b). Given the current lack of an apparent relationship between digital construction influence and automated problem-solving for task difficulty, the researcher accepted the null sub-hypothesis H3.4f0 due to the lack of an apparent relationship between digital construction influence and automated problem-solving to manage task difficulty. Future tool integration and automation can yield more optimal outcomes.

In addition to automated solutions, digital construction may also play a role in project managers' approach to other problem-solving domains. For example, H3.1f and H3.5f examined how specification changes can dynamically alter projects and propagate performance-related uncertainties. Chen et al. (2010) noted that these changes can propagate uncertainties. Experienced managers often foresee challenges from changes; however, unfamiliar construction methods may exceed intuition (Xia and Chan, 2012). In such scenarios, managers face manifold challenges that must be resolved to ensure the project is performed according to its baseline. Moreover, relying solely on implicit knowledge may be insufficient, necessitating the integration of image processing, machine learning, BIM nD models, and virtual reality to provide managers with a visual understanding of the project and guide them in contending with untried construction methods (Rahimian et al., 2020).

Similarly, BIM nD clash detection and simulation features can also visualise potential challenges arising from specification changes and unfamiliar construction methods, allowing project managers to familiarise themselves with these new approaches through simulation (van den Helm et al., 2010). Despite the potential benefits of deploying digital construction, Nigerian managers indicated it only marginally improves problem-solving for specification changes. This could be because of limited tool availability and reliance on tacit knowledge. The low correlations for H3.1f and H3.5f necessitate further investigation into aligning technology with construction problem-solving norms.

Digital technologies, such as BIM, UAVs, and GIS, have demonstrated potential benefits in gathering and analysing project information to comprehend problems (Cleden, 2017). For example, Wang et al. (2019) proposed integrating BIM and GIS to visualise complex site topography and proposed solutions for undulating terrain, aligning with construct H3.3f. However, the findings suggest that digital construction only moderately enhances problem-solving around information gathering and sequencing (H3.2f and H3.3f). This may be attributable to insufficient automated intelligence capabilities, which remain in the preliminary stages of construction compared with other fields (Brettel et al., 2014).

In contrast to the weak correlations for information gathering and sequencing, sub-hypothesis H3.6f exhibited a positive relationship with digital construction influence and was statistically significant at the 95% confidence level. This outcome aligns with the advances made using BIM nD models in the construction industry, indicating a collaborative approach to project management that results in a well-defined project scope during the planning stage (Sacks et al., 2016). Furthermore, when scope changes occur during construction, integrating additional digital tools into BIM nD models empowers project managers to evaluate and address the new scope, as confirmed in this study.

Sacks et al. (2020a) recommended monitoring digital tools to complement digital twin models. This would enable project managers to visualise the project scope in real-time. Rahimian et al. (2020) proposed gamification using virtual reality, BIM 3D models, and advanced computing techniques to enable managers to comprehend the project scope seamlessly. Certain researchers have adopted a more conservative approach to managing project-scope changes. For example, Wang et al. (2019) suggested complementing GIS with BIM nD to provide managers with additional tools to mitigate uncertainty from scope changes. These studies indicate that digital tools are crucial in enabling managers to handle uncertainties arising from scope changes during infrastructure construction. Moreover, the penetration of BIM in industry has ensured managers can manage scope uncertainty during construction over the last decade. Consequently, these advances could have influenced the study participants to concur that digital construction enabled them to resolve scope uncertainty challenges competently during mega-infrastructure construction.

Despite these capabilities, construction problem-solving remains experiential, relying on project managers' competencies developed through education and experience (Maylor and Turner, 2017). While strategies recognise the inherent complexity of mega-construction, standardised approaches have limitations, given each project's uniqueness (Shenhar and Dvir, 2008). Moreover, this highlights the need to align technologies with individual competencies to strengthen problem-solving. H3f reveals gaps and opportunities for aligning emerging technologies with construction problem-solving realities. Despite the demonstrated potential of digital construction, its adoption remains limited because of impediments, such as insufficient expertise and entrenched norms and practices. Further examination of the optimal integration of technologies and problem-solving processes is necessary to enhance megaproject delivery.

$H3f_1$ There is a positive relationship between digital construction's influence on project manager's problem-solving competence and digital construction augmenting project managers to solve complex problems during infrastructure construction

8.2 Conceptual Framework Validation

With the statistical phase fulfilled, this integral step encompassed direct interfacing with industry specialists to garner perspectives that would inform targeted augmentations of the conceptual framework and enhance its efficacy. Thus, a qualitative approach is preferred. First, it would be difficult for participants to comprehend the framework using a questionnaire if it were deployed.

The structured interview compensates for this shortfall because the interviewer apprises the participants of the pertinent particulars to ensure their unbiased opinions. Second, a structured interview permits the interviewer to gather information not part of the initial research.

The interviewer solicited their perspectives on the tentative conceptual framework (Figure 8.1), supporting project managers in handling complexity trajectories during construction. Based on these findings, the researcher implemented refinements to the framework and proposed that project managers should augment their decision-making, problem-solving, communication, and information management competence to manage dynamic complexity during mega infrastructure construction. Similarly, the researcher proposed that project managers should augment their communication, planning, coordination, and information management competence to manage structural complexity effectively. The findings align with suggestions from the literature, although this study expands upon and suggests that project managers' competence could be augmented through the adoption of digital construction. The results of the validation process are as follows:

8.2.1 Section I: Demographic Data of Participants

A Complexity Management Framework was formulated to facilitate project managers to effectively address the challenges intrinsic to large-scale construction projects. The evaluation process encompassed eight participants, with six derived from the initial research phase focused on framework validation, and two additional participants were subsequently enlisted to assess broader applicability. Table 8.7 delineates the details of industry specialists and their professional experience. Five participants presently occupied mid-level managerial roles and were actively engaged at construction sites, while three held senior managerial positions. Having outlined the participants’ composition, the ensuing sections elucidated their assessments of the framework's efficacy across pertinent dimensions.

Table 8.7 Participants' Demography

Participants	Position	Responsibility	Experience in Construction
P1	Project Manager	Overall project management and production	20
P2	Managing Partner	Strategic decision-making and resource allocation	28
P3	Site Manager	On-site coordination	12
P4	Site Manager	On-site coordination and management	7
P5	Project Manager	Resource management	17
P6	PM Consultant	Project advisory	31
P7	Consultant Structural Engineer	Structures expertise	22
P8	Project Manager	Construction management	15

8.2.2 Section II: Framework Clarity

Based on assessments by project managers, the complexity management framework designed for mega-construction has yielded consistently favourable outcomes across critical dimensions. The evaluation revealed that the framework enables project managers to navigate complex projects, yielding a mean score of 4.13. Moreover, the clarity of the competence development strategy earned a substantial rating of 4.00, affirming its efficacy. The applicability of the framework in addressing the challenges of megaprojects was evaluated with a score of 4.25, indicating its relevance to veritable construction practices.

Additionally, the participants' insights further illuminate the potential of the framework. Their comments suggested that integrating digital tools on-site (referred to as digital construction) could offer pivotal support to project managers by curtailing intricate predicaments that often arise during construction. P2 postulated that the proposed framework helps managers prioritise the most salient competence while proffering construction companies a more viable trajectory for managing complexities. Another participant lauded the framework's attempt to encapsulate the intricacies of the actual construction, thereby enhancing perceived clarity.

The cumulative average rating of 4.13 (presented in Table 8.8), coupled with managers' perspectives, underscores the remarkable resonance between the framework and project managers' exigencies. This endorsement underscores the framework's intrinsic value in navigating the intricate terrains associated with mega-construction projects.

Table 8.8 Evaluation of Framework Clarity

To what extent do you agree with the assertion that	Average ratings (1=SD, 2=D, 3=N, 4=and 5=SA)
Clearly defines the key interrelationships.	4.13
Clearly defines a strategy for competence development.	4.00
Clearly defines a pathway for complexity management.	4.13
Is relevant for actual construction practices	4.25
Average	**4.13**

8.2.3 Section III: Framework Applicability

Assessing the complexity management framework for construction project managers provides insightful information about its effectiveness and relevance. The framework's clarity and comprehensibility received an average rating of 4.13, indicating that managers found it clear. Similarly, its ease of use received a favourable rating of 4.00, confirming its user-friendliness. The relevance of the framework for developing skills received an average rating of 4.13, indicating that it aligns well with improved professional competence. Additionally, managers conferred an assessment of 4.25 for the framework's applicability in managing construction complexity, emphasising its usefulness in addressing complex challenges. Notably, the affirmative ratings extended to practical use with an average of 4.5, implying that managers were inclined to use the framework in their professional endeavours.

Further commentary from the participants highlighted the insightful findings. Two participants opined that notwithstanding the intent to deploy digital construction, the lack of client buy-in, low investment in digital tools, and reliance on available tools, not optimal tools, made the participants reluctant to employ digital construction. The last point could be a cause for concern, as construction companies cannot afford to provide the desired tools for every project manager, considering that project managers are like birds of passage floating in the industry. P6, an experienced consultant from the baby boomer generation, proposed utilising BIM nD for project conceptualisation as the most worthwhile application. This specialist preferred conventional on-site approaches based on intuition rather than digital construction.

Based on the above findings, the total average rating of 4.20 (Table 8.9) for applicability highlights managers' consistent endorsement of the framework's effectiveness and proclivity for competence development during mega-construction development.

Table 8.9 Framework Applicability

To what extent do you agree with the assertion that	**Average ratings (1=SD, 2=D, 3=N, 4=and 5=SA)**
The framework is easily comprehensible.	4.13
The framework is easy to use	4.00
The framework is relevant to competence development	4.13
The framework is relevant to complexity management practices.	4.25
Would you consider the proposed framework in your professional endeavour?	4.5
Average	**4.20**

Further Comments:

The insights derived from interviews conducted with proficient project managers actively engaged in formulating the complexity management framework have yielded valuable recommendations, enriching the potential enhancements of the framework. Among these participants, Participant 3 underscored the significance of adept problem-solving in comprehending and navigating intricate and ever-changing project dynamics. Nonetheless, Participant 3 also proposed the exclusion of this facet, asserting that decision-making inherently encapsulates the essence of problem-solving. In response, the researcher acknowledged this perspective while elucidating the distinction between problem-solving, which addresses specific challenges, and decision-making, which involves the selection of optimal courses of action to achieve project objectives. It was posited that integrating digital construction methodologies could effectively accommodate both dimensions, facilitating adept management of project complexity.

Participant 8 highlighted the potential of incorporating predictive analytics into the framework, thereby enabling anticipation of potential bottlenecks and bolstering the framework's proactive capabilities. Additionally, Participant 2 advocated integrating a feedback mechanism within the framework, thus affording it the agility to evolve in response to emerging complexities and ensuring continued pertinence over time. The researcher further expounded on these insights, elucidating how integrating digital construction methodologies enhances the capacity of the framework to overcome uncertainties and underscores its inherent adaptability, thus substantiating its dynamic nature.

Experienced project managers exhibited unanimous enthusiasm when seeking input on the practical application of the framework. Participant 4 expressed fervent interest, highlighting the framework's exhaustive insights as a pivotal tool for informed decision-making. Participant 3 concurred, recognising its potential as a foundational cornerstone for effectively managing project complexity. Similarly, Participant 5 lauded the framework's flexibility and practicability, envisioning its seamless integration into forthcoming projects.

Interestingly, the perspectives of the two project managers, who were not directly involved in the framework's development, also provided valuable contributions. Participant 6, despite lacking direct engagement, provided astute suggestions for enhancement and proposed integrating real-time progress tracking mechanisms to facilitate ongoing complexity assessments based on the current project status. In a slightly different vein, Participant 7 exhibited cautious interest when prompted about potential utilisation, underscoring the necessity to grasp the potential implications of implementation prior to adoption comprehensively.

In summary, the interview sessions underscored both the perceived value of the framework, as depicted in Figure 8.1 and its potential viability in pragmatic implementation. Simultaneously, these conversations illuminated avenues for further refinement and adaptation of the framework to suit real-world contexts. The culmination of these insights exemplifies the framework's potential to serve as a robust tool for effectively managing the complexity within project landscapes.

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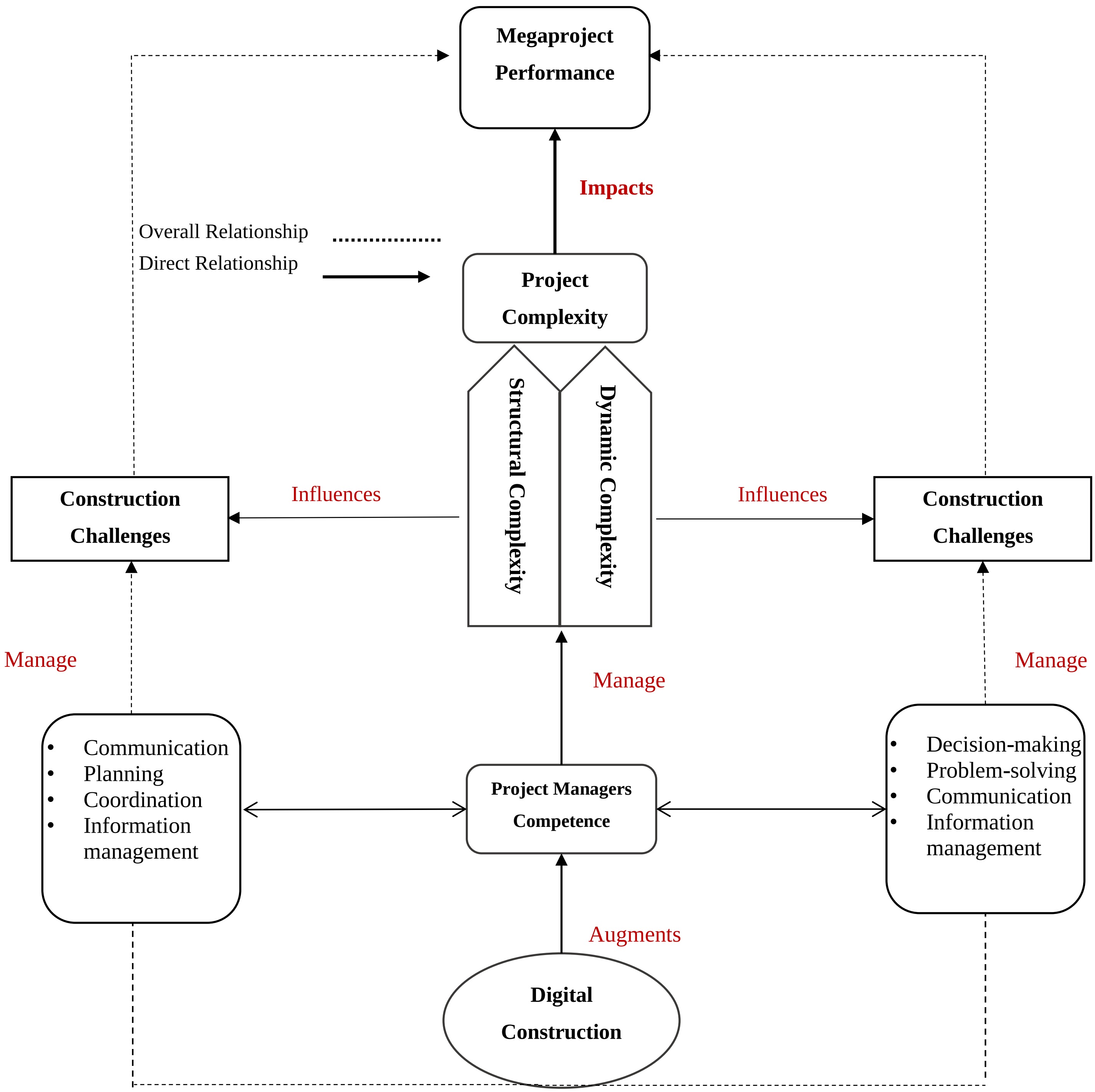

Figure 8.1 Project Manager's Competence Framework for Complexity Management.

Summary

In conclusion, this chapter comprehensively analyses the results, relating them to the literature and summarising the implications for theory and practice. The findings indicate that digital construction can augment project management competence in addressing the structural and dynamic complexities in mega-construction projects. However, the variability in the strength of the relationships highlights areas that require further research, adoption, and integration. Limitations in expertise, culture, and implementation readiness likely contribute to the gaps between the potential and actual impacts. Nevertheless, the overall positive correlations situate the results within the conceptual framework and point to the potential of digital construction if barriers can be overcome through training, incentives, and leadership initiatives. This comprehensive analytical discussion elucidates the current state and future directions to fully realise the benefits of digital construction for complexity management during mega-construction in Nigeria. Additionally, the participants' feedback affirmed the clarity and applicability of the framework in practical construction settings. Based on these findings, the next section presents the conclusions and recommendations for construction managers and companies regarding managing construction complexity in Nigeria. These recommendations prioritise adopting digital construction strategies and investing in digital tools to enhance project managers' competence in dealing with the inherent complexities of mega-infrastructure construction projects.

Chapter 9 Conclusion, Recommendations and Future Studies

This concluding chapter provides a synthesis of the extensive research undertaken to examine the potential of digital construction to enhance project management competence for mega infrastructure projects in Nigeria. It summarises how the study objectives have addressed the corresponding research questions established at the outset. The theoretical and practical contributions to knowledge are highlighted, along with the limitations and recommendations for future work. Overall, the chapter consolidates the multifaceted findings and perspectives of this PhD study, focusing on furthering construction project management through strategic digital augmentation.

9.1 Conclusion

This study began with an exploratory literature review to identify ways to improve Nigeria's mega-infrastructure development. The project managers' inability to manage the complexity inherent during the construction phase of this project type was an area of immediate concern. The researcher explored the proposed objectives through this study and addressed the research aim, as discussed below.

Achievement of Objective One

Evaluation of the intensity and nature of crucial complexity elements during mega-infrastructure construction.

Objective one identified the most intense complexity elements experienced by project managers during mega-infrastructure construction in Nigeria, addressing a critical knowledge gap in the literature. As established by prior research, the inherent complexity of megaprojects negatively affects cost, schedule, and performance outcomes (Ma and Fu, 2020). Scholars emphasise that project managers can navigate complexity more effectively by systematically identifying the predominant complexity drivers based on project type, geographical context, and lifecycle stage (Ghaleb et al., 2022). However, studies have not undertaken this contextual identification, specifically for Nigerian mega-infrastructure construction.

This study addressed this gap through an exploratory sequential mixed-methods study. An extensive literature review first delineated the key structural and dynamic complexity dimensions as critical foci for investigating the physical dimension of complexity management. Previous studies have identified a comprehensive set of complexity indicators. Employing these indicators, a questionnaire surveyed experienced Nigerian project managers in mega-construction, using factor analysis to categorise the indicators into intensity levels based on managers' ratings.

The findings revealed that the most intense drivers of structural complexity were task difficulty, sequence rigidity, multiple locations, site topography, and expansive project scope. Dynamic complexity was found to be driven most chaotically by the project duration and tempo, construction methods, team capabilities, and reliance on other projects. This study contributes to the empirical identification of complexity element intensities specific to the context of Nigerian infrastructure projects.

This contextual insight provides project managers with an enhanced understanding of proactive planning for managing these key complexity elements. The findings also inform the conceptual framework development and hypotheses examining whether digital construction can augment competence in managing these critical complexities. This study addresses a significant knowledge gap and establishes a foundation for exploring complexity management strategies tailored to Nigerian infrastructure projects.

In conclusion, this research makes notable theoretical and practical contributions by undertaking the first systematic intensity categorisation of complexity factors experienced during mega-construction projects within Nigeria's developing economy context. These findings give project managers and construction firms a heightened awareness of the most impactful complexity drivers to enable more effective navigation of inherent project challenges. This study provides project managers with contextual insights to strategically augment their competence in managing the unique complexity dynamics of mega-construction in Nigeria. The findings aptly address the first sub-research question and supply key complexity elements, warranting focus throughout the study.

Achievement of Objective Two

Identify the specific project manager competence factors that are most relevant and essential for effectively managing complexity during mega-infrastructure construction.

Chapter One highlighted the critical need for project managers to identify key competencies to effectively manage complexity during infrastructure development, aligning with the behavioural dimension of complexity management examined in this study. However, a gap exists in delineating the competencies most relevant to infrastructure projects in Nigeria's unique context.

Objective two addresses this gap through semi-structured interviews with experienced Nigerian project managers to elucidate the most critical competencies for mega-infrastructure projects. Rigorous narrative analysis of the transcribed interview data revealed that communication, planning, coordination, information management, decision-making, problem-solving, and team development were the foremost competency areas.

Notably, communication and planning have emerged as top competencies because of the numerous stakeholders involved and the extensive resources consumed in a structured manner on mega construction sites. Effective communication enables transparent information dissemination, team alignment, and the proactive resolution of issues. Meticulous planning allows optimal resource allocation, risk identification, and the development of contingency measures.

Semi-structured interviews provided rich empirical insights from seasoned project management professionals with expertise in Nigeria. Their perspectives strengthen the contextual validity of the identified critical competency factors. Participant diversity enhances the transferability of findings across various project types.

This study makes several important contributions to the existing literature. First, it equips project managers with insights into the most critical competence areas that require development to successfully navigate the complexity of Nigerian infrastructure projects. These findings can inform managers' training and professional advancement by delineating the locally relevant skills. Second, the results can guide academic project management programs to emphasise context-specific competencies in Nigeria's construction sector tailored curricula. Third, construction organisations can leverage the framework to systematise their approaches to the recruitment, training, and performance evaluation of project managers for complex megaprojects.

Furthermore, as one of the first investigations to focus solely on project management competence in Nigerian infrastructure development, this study establishes a foundation for further research on enhancing project management competence in developing countries. The contextual focus on Nigeria and infrastructure projects has a practical relevance.

In conclusion, Study α successfully established communication, planning, coordination, and other vital competencies for Nigerian mega infrastructure project managers. It addressed the knowledge gap around contextual competence and examined strategies to augment it for successful project delivery, answering sub-research question two.

Achievement of Objective Three

Investigate the influence of digital construction on project managers' competence in comprehending and navigating complex realities during infrastructure construction.

Objective three investigated whether adopting digital construction enhances project managers' competence in managing the complexity of large infrastructure projects in Nigeria. As a developing country that undertakes numerous massive and intricate construction initiatives, Nigeria must equip indigenous managers with the capability to steer complex endeavours. Digital construction entails thoughtfully integrating emerging digital technologies, such as BIM, sensors, automation, and analytics, in synergistic combinations tailored to the construction's unique contexts. Objective Three explored digital construction using a rigorous multi-phase mixed-methods approach. An exhaustive literature review synthesising over 90 sources has revealed increasing traction for digital construction over the past decade. However, empirical research on active construction sites still needs to be expanded, underscoring the need for in-depth enquiry in Nigeria's localised setting.

To address this gap, this study undertook extensive field observations across nine complex mega-construction projects in Nigeria. Open-ended on-site observation provided insights into managers leveraging context-specific digital technology combinations to enhance communication, planning, coordination, and monitoring when executing massive, intricate projects. This yielded revelatory qualitative evidence that competence augmentation occurs through digital construction in real-world practice. Quantitative surveys of 141 experienced Nigerian project managers further validated that digital construction significantly improves communication, planning, coordination, information management, decision-making, and problem-solving capabilities. Statistical analysis empirically demonstrated that digital tools enhanced coordination, planning, and communication competence, while enhancements to decision-making and problem-solving were less pronounced.

Objective three addresses this salient research gap by providing robust empirical evidence that digital construction positively transforms project managers' competence by drawing on multifaceted data sources encompassing literature, observations, and surveys. The findings establish that thoughtfully integrating emerging digital technologies in context-appropriate ways can equip indigenous managers with crucially augmented capabilities to address the complexity of mega-construction.

These meticulously substantiated findings have profound theoretical and practical implications for Nigeria's developing economy and broader sub-Saharan African context. Objective Three reveals the potential of digital construction as a strategically aligned project management approach tailored to distinctive regional construction needs. Practically, amplifying indigenous managers' digital capabilities can catalyse improved competence and performance as Nigeria expands its infrastructure. Comprehensive multi-stage findings suggest that digital construction can significantly impact project management practices. This underscores the need for continued scholarly enquiry and industry adoption of digital construction to augment project management efficacy and efficiency in navigating complexity during mega-construction.

Achievement of Objective Four

To examine the potential of digital construction to enhance project management competence in addressing structural complexity during mega-infrastructure construction.

Objective four of this study aimed to assess the potential of adopting digital construction practices to improve the competence of project managers in handling structural complexity within mega-infrastructure projects in Nigeria. In this context, structural complexity pertains to the inherent physical attributes that introduce difficulties during construction, such as task intricacy, inflexible work sequences, multiple work sites, and variable topography. Scholarly viewpoints, particularly those put forth by Dossick and Neff (2011), Xia and Chan (2012), and Nguyen et al. (2018), suggest that dimensions of project management competence encompassing communication, planning, coordination, and information management play a pivotal role in proactively mitigating these complexities.

The analysis involved rigorous quantitative examinations, employing correlation and regression techniques. The results highlight that digital construction practices are positively correlated with effectively breaking the extensive project scope into manageable work packages and simulations. This outcome was facilitated by immersive 4D/5D Building Information Modelling (BIM) visualisation and real-time collaborative capabilities. Integrating these digital techniques also demonstrates significant potential for enabling agile team formation and optimal scheduling of the necessary workforce, heavy machinery, and bulk materials at precise times and locations. This capability proved vital in addressing the challenges arising from task intricacy and sequence rigidity encountered on-site. Additionally, adopting digital construction led to enhanced communication and planning proficiency facilitated by instant interactions among dispersed project participants. However, effective utilisation of virtual teams across geographical boundaries remains constrained, highlighting the need for further investigation.

Furthermore, for intricate megaprojects encompassing multiple construction sites, robust empirical evidence indicates that adopting digital construction practices provides project managers with improved communication systems for efficient real-time interaction and coordination across distributed locations. Nevertheless, the correlation between problem-solving competence and digital construction adoption was weaker. This is likely attributable to the limited direct responsibilities of project managers for hands-on task execution during construction. Nonetheless, integrating monitoring and sensing digital technologies, such as unmanned aerial vehicles and remote sensors, exhibits promising potential in assisting project managers to continually monitor progress and proactively address the intricate challenges posed by demanding site topography and conditions.

In conclusion, the quantitative analysis provides pioneering empirical evidence supporting the positive and substantial association between adopting digital construction practices and the various dimensions of project manager competence required to comprehend and mitigate structural complexity in Nigerian mega-infrastructure projects. This finding aligns with the conceptual notion of aligning project team capabilities with megaprojects' inherent complexities. However, translating these competence enhancements into tangible performance improvements necessitates further rigorous examination through mixed-methods case studies and interviews. While the current quantitative findings affirm the hypothesised relationships, further research is essential to refine explicit strategies and implementation frameworks that can fully exploit the promising capabilities of digital techniques to significantly bolster project managers' abilities to address the critical factors that undermine the success of megaprojects.

Achievement of Objective Five

Determine the impact of digital construction on augmenting project managers' competence in managing the effects of dynamic complexity factors during mega-infrastructure construction.

This study conducted a systematic investigation to assess the influence of digital construction on enhancing project management competence to effectively handle the complex and dynamic factors inherent in mega-infrastructure projects, as outlined in objective five. Dynamic complexity arises from the intrinsic uncertainties and incomplete information characteristics of megaprojects, which limits their ability to anticipate and address challenges during construction. As a result, there is a recognised need to bolster project management competence by leveraging advanced digital techniques to make informed decisions and resolve intricate problems, offering a viable approach to managing uncertainty.

Through extensive empirical analysis, it has become evident that integrating digital construction can assist project managers in making informed decisions and in resolving challenges under uncertain conditions. However, the findings also revealed significant disparities and gaps that hinder the realisation of the anticipated transformative impact of digital construction on decision-making and problem solving.

Substantial disparities have surfaced between the theoretical potential of digital tools and their practical impact on enhancing project managers' abilities to make decisions and solve problems. These disparities are primarily attributed to obstacles that impede smooth adoption, including resistance rooted in organisational culture, deficits in expertise, and misaligned incentives. Overcoming these deeply ingrained challenges necessitates multifaceted interventions, including training, incentive restructuring, deliberate integration efforts, and a change-management approach that emphasises human aspects. Furthermore, the analysis highlighted that digital construction methods do not adequately equip managers to generate solutions for complex tasks or to facilitate the real-time transmission of decisions to stakeholders. This deficiency raises concerns, because streamlined information flow is essential for effective team collaboration.

Nevertheless, the analysis offers evidence that digital tools can support managers in framing decisions and implementing solutions that align with evolving project goals, particularly when dealing with complex construction methods. This heightened responsiveness assists in maintaining oversight even when confronted with unprecedented dynamics. While the advancement of automation and artificial intelligence holds the potential to elevate competence levels in proactively addressing challenges, current technologies have already enabled responsive, information-driven decision making despite prevailing uncertainties. Nonetheless, challenges persist due to hesitance and the need for expertise, diminishing the effectiveness of these capabilities.

This study contributes original evidence that digital construction has the potential to augment project management competence in dynamic complexity management. However, harnessing this potential to its fullest extent requires comprehensive multidimensional efforts to mitigate barriers to adoption that hinder the seamless integration of digital construction practices into the practicalities of construction projects.

Achievement of Objective Six

Develop a conceptual framework for complexity management tailored to the context of mega-infrastructure construction in Nigeria.

This study systematically developed an innovative conceptual framework to manage project complexity within contemporary mega-infrastructure development endeavours, as outlined in objective six. The foundation of this framework is firmly rooted in contingency management theory's theoretical principles. This theory underscores the strategic alignment of project management systems, processes, and emerging digital technologies to effectively target and address the multifaceted complexity factors inherent in megaconstruction projects. This framework was developed through a comprehensive critical review that synthesised and integrated pertinent concepts, models, and empirical findings from scholarly literature. This encompasses project complexity analysis, managerial competence frameworks, cutting-edge complexity management, technological approaches, and best practices.

Initial exploratory research employed quantitative and qualitative methods to identify and prioritise the primary structural and dynamic complexity factors prevalent in Nigerian mega-construction projects. This preliminary empirical analysis offers contextual insights and the information necessary for the data-driven construction of a conceptual framework. The framework proposes that a thoughtful embrace of digital construction, involving the purposeful integration of advanced digital technologies, such as virtual design and construction through building information modelling, real-time monitoring through the Internet of Things sensors, standardisation via automation and robotics, and predictive insights through advanced data analytics, constitutes a strategically aligned approach with significant potential to significantly enhance project management capabilities in managing mega-construction complexities in a responsive, ethical, and cost-efficient manner.

Based on survey data collected from construction experts, extensive statistical hypothesis testing and correlation analysis robustly validated the framework. This validation was achieved by affirming the presence of substantial positive empirical connections between the adoption of digital construction, improved project management competence across pertinent dimensions, heightened capacity for proactive complexity management, and overall enhancements in crucial project performance metrics. The conceptual relationships that formed the foundation of the proposed framework were substantiated through empirical investigation.

Furthermore, in-depth interviews with eight construction industry experts in Nigeria—individuals well-acquainted with the tools, techniques, and challenges inherent in the megaproject landscape—augmented the validation process. Their insights substantiated the framework's perceived conceptual clarity, direct applicability within real-world project contexts, and the potential for phased implementation as a pragmatic approach to navigating and mitigating multifaceted mega-construction complexities within the Nigerian construction sector. Participant feedback has also identified valuable areas that require ongoing framework refinement, including integrating predictive analytics, real-time progress tracking sensors with location awareness, and interactive worker feedback loops through interdisciplinary technological integration efforts.

Collectively, this inclusive mixed-methods approach, encompassing both deductive development and inductive expert validation, underscores the rigorous empirical foundation of the final framework in industrial realities. It aligned tightly with the contemporary mega-construction environment, offering indigenous project managers tailored guidance to effectively leverage digital technologies. This guidance is intended to address the primary complexities inherent in mega-construction, significantly enhancing overall project performance outcomes.

In summary, the systematic progression from literature-based development to qualitative practitioner validation attests to the considerable potential of this conceptual framework. Its structured approach aims to directly address objective six to formulate an innovative project complexity management strategy that is globally cutting-edge, contextually responsive, and poised to address foreseeable future needs within the domain of mega-infrastructure projects. Through comprehensive empirical validation, this framework contributes significantly to advancing both theoretical understanding and practical best practices.

9.2 General Conclusion

This study systematically investigated the potential of adopting digital construction to enhance project management competence in dealing with multidimensional complexity during mega-infrastructure development in Nigeria. Through a comprehensive multi-phase mixed-methods approach, this investigation establishes that well-executed digital construction could significantly enhance project managers' competence in navigating and controlling the intricate structural and dynamic complexities inherent in mega-construction projects, addressing the broad research question.

Specifically, the extensive analysis presents empirical evidence that the strategic integration of digital construction significantly improves project management competencies such as communication, planning, coordination, information sharing, decision-making, and problem-solving. These improvements are particularly relevant when addressing challenges arising from dispersed teams, interdependencies, uncertainties, and lack of real-time project visibility. Consequently, digital construction empowers efficient oversight, control, and adaptable responsiveness among project managers.

Nevertheless, notable gaps in realising the full potential of digital construction were identified, often attributed to persistent obstacles, such as deficits in expertise, entrenched norms, and misalignments in incentives for adoption. Overcoming these challenges requires concerted efforts across technological advancements, process enhancements, policy adjustments, and cultural shifts—a sole focus on technical risks and neglecting the vital human dimensions essential for successful integration.

Nonetheless, this research employs triangulated approaches, including literature synthesis, observations, and surveys, providing substantial evidence that digital construction represents a strategically viable approach for enhancing competence within the unique construction context of the developing world. This endeavour holds significance in both theoretical and practical realms. It offers a balanced evaluation of the potential offered by digital construction, while acknowledging the existing constraints that necessitate ongoing progress. In doing so, it enriches our comprehension of digitally enabled project management suited to the demands of the fourth industrial revolution. In addition, the proposed framework serves as a valuable reference point for harnessing the potential of human-centred digital augmentation to address complex construction challenges. This designates digital construction as a phenomenon that deserves further research and adoption to enhance indigenous practices.

In conclusion, with careful context-sensitive implementation, digital construction presents a viable avenue for proficiently managing pervasive complexity, ushering in an era of sophisticated project management empowered by digitally enabled capabilities specifically designed to address the realities of mega-construction. This pioneering effort sheds light on a significant phenomenon at the intersection of construction's digital transformation in developing economies, answering the broad research question. This study makes meaningful contributions to academia and industry by generating original empirical insights and offering a well-rounded perspective on enhancing indigenous project management through digitally enhanced competencies.

9.3 Contribution to Knowledge

The current doctoral research has significantly enhanced our understanding of the complexities of managing large-scale infrastructure projects. The multifaceted findings presented in this study advance the theoretical understanding and offer practical insights that contribute to various critical aspects of project management and construction practices. The following section highlights the key contributions of this study:

Redefining Digital Strategies for Complexity Management

This study makes a ground-breaking contribution by introducing a novel theoretical and practical approach to digital construction to manage the complexity of mega-construction projects. Through an extensive critical literature review synthesizing over 90 sources, this research develops the digital construction concept involving thoughtful integration of technologies to create a human-centred approach to managing complexity.

The study introduces an unconventional lens to examine megaproject complexity trajectories, envisioning sophisticated techniques, such as virtual construction, real-time monitoring, and predictive analytics, as enablers that can profoundly elevate coordination, communication, planning, decision-making, and oversight when synergistically combined. By reconceptualising manufacturing digital strategies for construction, this research introduces an innovative competence enhancement framework tailored to managing intricacies in megaprojects that have not been rigorously explored before. The proposed reframing of digital construction opens new avenues for scholars and practitioners to consider thoughtfully harnessing technology as a strategic capability to enhance human abilities and address escalating mega-construction complexities.

This timely undertaking illuminates a pioneering complexity-management approach that leverages human-centred digital strategies designed explicitly for the construction industry's distinctive needs. This multidimensional contribution provides crucial theoretical and practical insights into managing mega-construction intricacies by cultivating sophisticated, digitally enabled project management paradigms in the 21st century.

Empirical Validation of Digital Construction Efficacy

This doctoral dissertation significantly contributes to understanding the role of digital construction practices in improving project management competence, particularly in complex Nigerian mega-construction projects. This study provides robust empirical evidence on the impacts of digital construction through a comprehensive mixed methods approach involving literature analysis, field observations, surveys of 141 project managers, semi-structured interviews, and quantitative hypothesis testing. The pivotal nature of this contribution rests on the robust empirical evidence generated through meticulous mixed methods. Rather than relying solely on theoretical conjectures, this study adopts a comprehensive empirical approach involving literature analysis, field observations, surveys, interviews, and hypothesis testing to investigate the research proposition within the Nigerian context.

The findings offer concrete validation that integrating contextualised digital technologies through a human-centred digital construction approach impacts project management capabilities, including communication, planning, coordination, decision-making, monitoring, and information management. This research underscores the considerable yet underutilised potential of digital construction in addressing mega-construction intricacies by bridging the gap between theory and practice with invaluable, data-grounded insights.

The evidence shows how purposeful digital technique combinations can optimise various mega-construction aspects, including collaboration, work and information flows, oversight, responsiveness, and adaptability. This study provides construction firms and project managers with a reliable foundation for making informed decisions about technology integration by generating multidimensional empirical data showing the significant enhancement of competence in digital construction.

This study delivers vital empirical confirmation through extensive mixed-methods data triangulation that adopting digital construction can transform project management efficacy in addressing inherent mega-construction complexity challenges.

Categorisation of Complexity Elements

This research makes a significant contribution by developing an original methodology to categorise the complexity factors unique to infrastructure projects in Nigeria. Rather than relying on traditional classification methods, this study's novel approach examined the intensity of each complexity factor. This provides a new perspective to understand the intricate complexities of infrastructure projects.

The careful categorisation process reveals the most complex elements that hinder project manager performance. This study elucidates the most severe challenges project managers face when delivering mega-infrastructure projects in Nigeria. This deepens existing knowledge by comprehensively understanding the complexities endemic to the Nigerian infrastructure context.

The sophisticated categorisation of complexity factors is a notable addition to the literature. The methodology and findings significantly advance the conceptualisation of multifaceted complexities that underscore infrastructure project management in Nigeria. The findings enriches the field by providing targeted insights into the most impactful complexities encountered by project managers, clarifying the intricate mega-construction management landscape in Nigeria.

Contextualised Competence Development

This doctoral dissertation significantly contributes to the discourse on developing competence in managing complexity in Nigeria. The current study presents a tailored framework for building competence by identifying the specific skills required for infrastructure construction. It also emphasises the importance of adopting digital construction techniques to enhance these competencies, thereby providing a theoretical and practical foundation for project managers to navigate complex challenges successfully.

This research sheds light on the potential of digital strategies to equip project managers with the contextualised capabilities necessary to manage the intricacies of infrastructure projects in Nigeria. Furthermore, this study enriches our understanding of competence building within complexity management in developing countries. The contextualised competence framework enables Nigerian project managers to cultivate the precise expertise required for infrastructure construction and adopt digital construction techniques.

Moreover, this Ph.D. thesis advances our project management knowledge, particularly concerning mega-infrastructure projects. The research redefines digital strategies, validates their efficacy, introduces new categorisation methods, and contextualises competence development. These insights provide valuable guidance for the construction industry and offer practical solutions for managing the complexity of infrastructure projects.

This impactful research represents a valuable contribution to project management knowledge, particularly regarding effective complexity management in developing countries. The multifaceted insights presented in this dissertation will undoubtedly guide future studies and practical applications in the industry, further advancing our understanding of managing the complexity of infrastructure projects.

9.4 Limitations

This study presents robust empirical evidence of the potential of digital construction to significantly improve project management competence for mega-construction projects in Nigeria. However, certain inherent limitations offer valuable opportunities to advance this research through additional scholarly endeavours. Notably, geographic concentration solely in Nigeria may be perceived as restrictive, although the involvement of prominent international firms with globally sourced project teams partially mitigates this limitation. To gain broader perspectives and enrich our understanding, expanding research to cover more diverse regions and project settings would be beneficial.

Furthermore, the quantitative questionnaire methodology had limitations in determining the specific digital tools used by each respondent. As variations in tool sophistication could affect functionality and impact, exploring emerging innovations, such as AI and virtual reality, might uncover additional possibilities beyond the established tools examined. Moreover, the survey design precluded ascertaining the precise number and type of tools available to each manager.

However, extensive observations have confirmed the widespread adoption of digital tools in mega-construction projects. This study investigated the influence of digital construction on competence, rather than evaluating individual tools, highlighting its key strengths.

Incorporating project stakeholders' perspectives beyond those of the project managers can provide more comprehensive insights. Concentrating exclusively on mega-infrastructure projects offers a valuable focus; however, extending the enquiry across various project types could reveal additional complexities and competence requirements. Furthermore, the narrow focus on the construction phase constrains the investigation to a limited lifecycle perspective; investigating transformations across project lifecycles offers holistic insights.

While acknowledging the assumptions made in the quantitative analysis regarding participants' honesty and objectivity, addressing them through rigorous qualitative enquiry could enrich this research. In particular, the reliance on self-reported data from project managers regarding their perceived competence levels presents a limitation, as managers may overestimate or misjudge their proficiency across competencies. The inclusion of multi-rater competency assessments from supervisors, clients, or team members could have provided more objective competence measurements to validate the self-reported findings. This dependence on self-appraised competence data represents a notable limitation.

By concentrating primarily on time and budget, this study overlooked the potential impact of digital construction on other objectives such as quality, safety, and sustainability. Analysing more performance indicators could provide more comprehensive strategies. Although the methodology demonstrated relationships between variables, it did not explicitly test the performance outcomes, which would be a valuable direction for future work.

This pioneering study makes significant contributions by offering original empirical evidence that substantiates the potential of digital construction to enhance project management competence. However, the limitations highlighted here create avenues for impactful research to advance the field. Substantial opportunities exist for current and future researchers to address these limitations through rigorous, interdisciplinary, mixed methods and approaches encompassing technology, processes, policies, culture, and organisational contexts. Such research initiatives will profoundly enrich academic and practical understanding and establish pathways to fully unlock the potential of human-centred digital technologies in fundamentally transforming construction project management to navigate multifaceted complexity dynamics. The field can progressively advance toward realising next-generation digitally enhanced project management capabilities through extensive interdisciplinary research.

9.5 Recommendations

Realising digital construction's transformative potential to enhance project management competence necessitates collaborative efforts across diverse industry stakeholders. In the context of the construction sector's historical reluctance to embrace change, the enactment of deliberate legislation, coupled with incentives, emerges as a crucial catalyst for comprehensive supply chain-wide investment in digital construction, expediting assimilation. This strategic approach empowers project managers with sophisticated tools to navigate intricate complexity dynamics. The effectiveness of government mandates in driving technology adoption across various industries underscores the potential value of a carefully implemented policy-driven strategy. Governments could provide tax incentives, subsidies, and preferential bidding for infrastructure projects showcasing a minimum threshold of digital construction adoption across planning, design, and construction phases, thereby incentivising and accelerating mainstream implementation.

Professional associations, such as the Project Management Institute, should proactively publish guidelines and standards documents formally defining and endorsing the "digital construction" concept. This initiative aims to drive recognition and offer construction firms specific guidance on strategically integrating tools to enhance competence. Additionally, introducing dedicated technology liaison roles within project teams facilitates the seamless integration of digital construction across projects. Furthermore, construction sites should incorporate digital observer roles to document processes and pain points, analyse data, and provide user insights. These roles contribute to refining systems and processes, maximising the benefits of digital construction.

Ensuring widespread technical proficiency throughout the construction value chain is paramount, given that skill gaps can significantly impede the effective on-site utilisation of emerging technologies. Consequently, establishing fundamental digital literacy could be mandated as a prerequisite for specialist subcontractors, encouraging active participation in the holistic deployment of digital construction. Implementing maturity certifications further aligns technical competencies with project requirements, enabling optimal configuration. Moreover, advancements in automation capabilities, through techniques like artificial intelligence and machine learning, hold the potential to unlock advanced decision support and problem-solving functionalities, significantly enhancing management skills to address uncertainties. Collaborative efforts spanning technical and social disciplines are indispensable for realising the full potential of digital construction through pragmatic yet ingenious, human-centred design.

Firms should invest in user experience research and shadowing exercises with project managers to uncover needs and gain insights into psychology, behaviour, and organisational dynamics. This informs the business case and design requirements for developing customised, user-friendly digital tools tailored to construction environments. Similarly, digital tool manufacturers should offer free trials, customised pilots, and on-site support to facilitate hands-on learning, increasing exposure to potential business benefits of new technologies, thereby promoting evaluation and adoption.

In academia, a crucial role lies in evolving construction education curricula to emphasise competence development and complexity management. This involves providing students extensive exposure to digital construction theory and practice, equipping the next generation to enter the project management profession with enhanced competence to effectively utilise tools in practical scenarios.

In conclusion, this comprehensive strategy, comprising well-conceived policies, educational initiatives, interdisciplinary research, increased automation, and forward-looking pedagogical approaches, provides a viable roadmap for addressing ongoing challenges. The assimilation of these strategies can transform project management paradigms by integrating sophisticated digital technologies that are attentive to human needs, addressing the multifaceted dynamics of construction complexity. The realisation of this vision could be actualised through interdisciplinary collaborative efforts that cohesively align technological refinements, behavioural insights, ethical considerations, and a nuanced understanding of local contexts, enabling the construction industry to progress toward digitally enabled next-generation project management practices offering enhanced oversight, communication, coordination, and decision-making capabilities.

9.6 Future Studies

This study contributes significantly by providing original empirical evidence concerning the potential of digital construction to enhance project management competence in the context of mega-construction projects in Nigeria. However, substantial opportunities exist for future scholarly endeavours that can substantially broaden our understanding of digital construction and uncover pivotal pathways to fully realise its latent potential for transforming project management.

First, it is evident that sporadic deployment of digital tools has hindered holistic integration throughout the construction lifecycle. In-depth studies identifying and addressing systemic bottlenecks that obstruct comprehensive project lifecycle adoption can provide invaluable insights. As a future research priority, the researcher intend to undertake multiple case studies of infrastructure projects in Nigeria to uncover specific barriers across project phases and derive policy recommendations for streamlining digital construction implementation. Such efforts could pave the way for evidence-based policies to accelerate practical implementation. Additionally, investigating the previously unexplored impact of digital construction on project management competence across a spectrum of project goals could enrich scholarly comprehension of how digital tools facilitate overall competence enhancement.

Furthermore, extensive research on the untapped potential of digital construction to bolster project management competence across broader project performance indicators, including quality, productivity, safety, sustainability, and stakeholder management, would provide a broader perspective. Comprehensive investigations of this nature could aid in dismantling persistent barriers to adoption, while offering essential insights to construction firms and project managers to effectively embed context-specific digital construction strategies as integral management methodologies.

Rigorous exploratory case study research that unveils effective combinations of digital tools tailored to specific project types and settings across the infrastructure life cycle can yield critical insights into pragmatic implementation. Additionally, empirical examinations of interactions between diverse project stakeholders and digital tools, analysed from a systems perspective, could uncover vital behavioural insights. Such insights would help shape human-centred change management strategies to facilitate the successful assimilation of digital construction.

Research endeavours focused on investigating and establishing pathways for harmonising digital construction with complementary project management methodologies, such as Lean Construction, Agile, and sustainability-driven approaches, have immense potential. This potential lies in holistically accelerating digital integration through synergistic implementation strategies that align with local contextual needs and realities in the developing world. Moreover, a comprehensive exploration of the interrelationships between human intuition, ethics, and digital augmentation capabilities represents a crucial area that warrants thorough examination to shape well-balanced ethical adoption protocols.

Cross-disciplinary collaborative approaches encompassing domains, such as computing, information systems, ergonomics, psychology, and social sciences, also promise to enhance the functionality and interoperability of digital tools. These approaches can facilitate purpose-fit and human-centred design of technologies, policies, and processes. Construction project management practices can be profoundly transformed by harnessing diverse research endeavours spanning technology, organisational behaviour, culture, policy, and processes.

In conclusion, this multifaceted roadmap encompassing socio-technical dimensions, behavioural factors, user-centric design requirements, synergies among complementary tools, competence interconnections, adoption policies, and emerging construction technologies points towards the direction of high-value research in the coming decades. Insights from these initiatives have the potential to reveal the latent capabilities of digital construction. This unveiling could usher in a new era of project management that integrates and augments sophisticated human capabilities through context-specific, ethical, and human-centred digital adoption, which positions digital construction at the core of the next-generation construction practices.

Summary

In conclusion, this chapter provides a comprehensive discussion of the research findings, situates the results within the existing literature, and outlines meaningful theoretical and practical implications stemming from this study. The key conclusions demonstrate that adopting digital construction has substantial potential as an impactful project management competence enhancement strategy, although further work is required to fully harness its benefits. Thoughtful acknowledgement was given to the limitations of the geographic setting and scope, along with recommendations encompassing policy, practice, pedagogy, and future research directions focused on digital construction, competence elevation, and complexity management. Ultimately, this chapter integrates the fragmented components of extensive research into cohesive narratives. This highlights the vital role of digital construction in shaping the next era of sophisticated project management capabilities powered by digitally enabled competence to address complexity. It points to pathways for successfully delivering mega-projects in Nigeria's developing economy through human-centred digital transformation.

This study reveals digital construction as an emerging strategy that could profoundly transform project management competence through human-centred technological integration tailored to construction's unique complexities. The original empirical evidence substantiated here affirms the immense yet latent potential of digital tools to enable managers to effectively navigate escalating mega-project complexities when deployed thoughtfully. Realising this immense potential necessitates interdisciplinary collaborative efforts spanning technology, processes, culture, and policy dimensions. Although an intricate process, digital construction represents a strategically viable avenue for constructing sophisticated project management capabilities powered by digitally enhanced competence. Thereby, when comprehensively embraced, digital construction can usher the construction sector into a new era of streamlined, responsive, and competent project oversight capable of mustering multidimensional complexities and successfully delivering intricate large-scale projects.

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Appendix A (Study α Questionnaire)

Participant Information Sheet

Dear Participant,

Thank you for agreeing to participate in this questionnaire survey in connection with my PhD dissertation/research at the University of Nottingham Ningbo. The project studies how complexity (difficulty) could be managed on mega infrastructure projects during the construction phase. Theoretically and in practice, project managers have continued to struggle with the dire effects of complexity on mega infrastructure projects due to the limitations of current project management strategies available during the construction phase. In this survey, we appreciate that you rank each element of complexity (difficulty) as it applies during the construction phase of mega infrastructural projects.

Your participation in the survey is voluntary. You are able to withdraw from the survey at any time and to request that the information you have provided is not used in the project. Any information provided will be confidential. Your identity will not be disclosed in any use of the information you have supplied during the survey.

The research project has been reviewed according to the ethical review processes in place in the University of Nottingham Ningbo. These processes are governed by the University's Code of Research Conduct and Research Ethics. Should you have any question now or in the future, please contact me or my supervisor. Should you have concerns related to my conduct of the survey or research ethics, please contact my supervisor or the University's Ethics Committee.

Yours truly,
Iliyasu Abba Abdullahi

Contact details:
Student Researcher: Iliyasu Abba Abdullahi – IliyasuAbba.Abdullahi@nottingham.edu.cn
Supervisor: Georgios Kapogiannis – Georgios.Kapogiannis@nottingham.edu.cn
University Research Ethics Committee Coordinator, Ms Joanna Huang
(Joanna.Huang@nottingham.edu.cn)

Participant Consent Form

Project title — Managing Project Complexity: A study on the adoption of Digital Construction Strategy to improve performance on Mega Infrastructure Projects
Researcher's name: Iliyasu Abba Abdullahi
Supervisor's name: Georgios Kapogiannis

- *I have read the Participant Information Sheet and the nature and purpose of the research project has been explained to me. I understand and agree to take part.*
- I understand the purpose of the research project and my involvement in it.
- I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.
- I understand that while information gained during the study may be published, I will not be identified and my personal results will remain confidential.
- I understand that data will be stored in accordance with data protection laws
- I understand that I may contact the researcher or supervisor if I require more information about the research, and that I may contact the Research Ethics Sub-Committee of the University of Nottingham, Ningbo if I wish to make a complaint related to my involvement in the research.

Contact details:
Student Researcher: Iliyasu Abba Abdullahi – IliyasuAbba.Abdullahi@nottingham.edu.cn
Supervisor: Georgios Kapogiannis – Georgios.Kapogiannis@nottingham.edu.cn
University Research Ethics Committee Coordinator, Ms Joanna Huang
(Joanna.Huang@nottingham.edu.cn)

○ Yes, I consent to participate
○ No, I decline to participate

Background Information

Your professional affiliation is ______________

○ Architecture
○ Builder
○ Civil Engineering
○ Planner

- ○ Project Management
- ○ Quantity Surveyor
- ○ Other ______________

How many years of experience do you have as a project manager?

- ○ Less than 5 years
- ○ Between 6 and 10 years
- ○ Between 11 and 15 years
- ○ Between 16 and 20 years
- ○ Between 21 and 25 years
- ○ Between 26 and 30 years
- ○ Over 30 years

What type of infrastructure development do you mostly participate in?

- ☐ Road Network Construction
- ☐ Rail Network Construction
- ☐ Chemical Plants Construction (i.e Refinery, Fertilizer)
- ☐ Utility Facilities (i.e. dams, power station, water treatment plant)
- ☐ Building Infrastructure (i.e. Airports, Hospitals Stadium)

Which region are your projects mostly domiciled?

- ○ Africa
- ○ Asia
- ○ Europe
- ○ Middle East
- ○ North America
- ○ South America
- ○ Oceania
- ○ Others ________________

Structural Complexity

Structural Complexity elements on Mega Infrastructure Projects

When completing this survey, consider yourself on a construction site developing a large infrastructure project and answer from a general perspective. Your thoughts should not only be limited to the projects you were involved in while determining to what extent the project component potentially contributes to complexity. **The strength of influence is between 0 (no intensity) and 10 (extreme intensity). Note structural complexity entails difficulty that reverberates due to the structural characteristics of the project.**

To what extent could the project feautures in the list below potentially contributes to complexity intensity during the construction phase of mega infrastructure projects?

	0	1	2	3	4	5	6	7	8	9	10
Project Height	○	○	○	○	○	○	○	○	○	○	○
Type of Structure	○	○	○	○	○	○	○	○	○	○	○
Site Perimeter	○	○	○	○	○	○	○	○	○	○	○
Project Density	○	○	○	○	○	○	○	○	○	○	○
Number of Elements	○	○	○	○	○	○	○	○	○	○	○
Number of Project Participants	○	○	○	○	○	○	○	○	○	○	○
Required Engineering Hours	○	○	○	○	○	○	○	○	○	○	○
Project Budget	○	○	○	○	○	○	○	○	○	○	○

Whilst carrying out task and activities on site, to what extent could the elements in the table below potentially contribute to complexity intensity at the construction phase?

	0	1	2	3	4	5	6	7	8	9	10
Numerous Task	○	○	○	○	○	○	○	○	○	○	○
High Variety of Task	○	○	○	○	○	○	○	○	○	○	○
Difficulty of Task	○	○	○	○	○	○	○	○	○	○	○
Project Scheduling	○	○	○	○	○	○	○	○	○	○	○
Rigidity of Sequence	○	○	○	○	○	○	○	○	○	○	○
Quality Requirement	○	○	○	○	○	○	○	○	○	○	○
Construction Method	○	○	○	○	○	○	○	○	○	○	○

	0	1	2	3	4	5	6	7	8	9	10
Lack of technical knowhow	○	○	○	○	○	○	○	○	○	○	○

To what extent could the project characteristics potentially contribute to the intensity of project complexity

	0	1	2	3	4	5	6	7	8	9	10
Project Scope	○	○	○	○	○	○	○	○	○	○	○
Dispersed Remote Teams	○	○	○	○	○	○	○	○	○	○	○
Multiple Locations	○	○	○	○	○	○	○	○	○	○	○
Multiple Time zones	○	○	○	○	○	○	○	○	○	○	○
Site Topography	○	○	○	○	○	○	○	○	○	○	○

To what extent could the inter-relationship between project components affects the overall complexity on a project

Not Intense Extremely Intense

0○ 1○ 2○ 3○ 4○ 5○ 6○ 7○ 8○ 9○ 10○

The dependence amongst different project components contributes to complexity intensity on projects to what extent.

Not Intense Extremely Intense

0○ 1○ 2○ 3○ 4○ 5○ 6○ 7○ 8○ 9○ 10○

Dynamic Complexity elements on Mega Infrastructural Project

Dynamic Complexity elements on Mega Infrastructural Project

When completing this section, try to envisage that moment when uncertainties, and incessant change of project variables rendered you helpless and incapable whilst at the construction stage of an infrastructure project. Your thoughts do not have to be limited to just your personal experience. **The strength of influence is between 0 (no influence) and 10 (high influence). Dynamic complexity entails difficulty that leads to change and uncertainties.**

To what extent could the project features below potentially contribute to change and uncertainties, leading to complexity during the construction phase?

	0	1	2	3	4	5	6	7	8	9	10
Project Duration	○	○	○	○	○	○	○	○	○	○	○
Project Tempo	○	○	○	○	○	○	○	○	○	○	○
Construction Methods	○	○	○	○	○	○	○	○	○	○	○
Uncertainty in Methods	○	○	○	○	○	○	○	○	○	○	○
Reliance on Other Projects	○	○	○	○	○	○	○	○	○	○	○
Project Teams Capability	○	○	○	○	○	○	○	○	○	○	○
Geological Condition	○	○	○	○	○	○	○	○	○	○	○
Immediate Environment	○	○	○	○	○	○	○	○	○	○	○
Deployment of Plants	○	○	○	○	○	○	○	○	○	○	○
Deployment of Workers	○	○	○	○	○	○	○	○	○	○	○
Regulations	○	○	○	○	○	○	○	○	○	○	○

The deegre to which any of the following project setout goal could influence change and uncertainty during the construction phase

	0	1	2	3	4	5	6	7	8	9	10
High Number of Goals	○	○	○	○	○	○	○	○	○	○	○
Lack of Clear Project Goal	○	○	○	○	○	○	○	○	○	○	○
Multiple Project Goals	○	○	○	○	○	○	○	○	○	○	○
Variety of Perspective	○	○	○	○	○	○	○	○	○	○	○
Form of Contract	○	○	○	○	○	○	○	○	○	○	○

To what extent could the project scope potentially contribute to uncertainty and change in activities thereby translating to complexity?

	0	1	2	3	4	5	6	7	8	9	10
Scope of Work	○	○	○	○	○	○	○	○	○	○	○
Disperse Teams	○	○	○	○	○	○	○	○	○	○	○
Multiple Location	○	○	○	○	○	○	○	○	○	○	○
Multiple Timezones	○	○	○	○	○	○	○	○	○	○	○
Form of Contract	○	○	○	○	○	○	○	○	○	○	○

Whilst on the construction phase of a project, how often does any of these elements significantly contribute to uncertainty and change in scope leading to complexity?

	0	1	2	3	4	5	6	7	8	9	10
Ambiguity of Scope	○	○	○	○	○	○	○	○	○	○	○
Uncertainty of Scope	○	○	○	○	○	○	○	○	○	○	○
Change in Project Scope	○	○	○	○	○	○	○	○	○	○	○
Change in Project Specification	○	○	○	○	○	○	○	○	○	○	○
Inability to Estimate Accurately (Timeline and Budget)	○	○	○	○	○	○	○	○	○	○	○
Quantity of Information to analyse	○	○	○	○	○	○	○	○	○	○	○
Number of Information Source	○	○	○	○	○	○	○	○	○	○	○

Would you choose to participate in the next phase of the research

- ○ Yes
- ○ No
- ○ Maybe

Appendix B (Study β – Interview Questions)

1. Describe your role during the construction phase of mega infrastructure projects
2. What are the key competencies you bring along to every project?
3. From the table below is an extensive list of project management competence. Could you rank between none (0) to very important (10) the level of importance of each to a project manager at the construction phase of mega infrastructure projects

Competence	0 (***none***) and 10 (***very important***)										
	0	1	2	3	4	5	6	7	8	9	10
Leadership											
Planning											
Directing											
Motivates team											
Issues and conflict resolution											
Effective decision-making											
Communication											
Supervising											
Interfacing and coordinating											
Delegating											
Administering											
Negotiation											
Aptitude											
Confidence and commitment											
Proactive											
Open-mindedness											
Trustworthy											
Analytical thinking											

4. From the table above, in your opinion, could you select the top seven competence elements important to you when constructing mega infrastructure.
5. Have infrastructure projects got more complex over the years?
6. Background Information

- Your profession,
- Project type you participate in,
- Years of experience
- Your roles on this project

Appendix C (Study δ Questionnaire)

Participant Information Sheet
Managing Infrastructure construction complexity through Digital construction.

Dear Participant,

Thank you for agreeing to participate in this questionnaire survey in connection with my Ph.D. dissertation/research at the University of Nottingham Ningbo. The project is a study to understand if Digital Construction Strategy's adoption could increase project management competence to manage complexity effects during infrastructure construction.

Your participation in the survey is voluntary. You can withdraw from the survey at any time and request that the information you have provided is not used in the project. Any information provided will be confidential. Your identity will not be disclosed in any use of the information you have supplied during the survey.

The research project has been reviewed according to the ethical review processes in place at the University of Nottingham Ningbo. These processes are governed by the University's Code of Research Conduct and Research Ethics. Should you have any questions now or in the future, please contact my supervisor or me. Should you have concerns about my conduct of the survey or research ethics, please contact my supervisor or the University's Ethics Committee.

Yours truly,
Iliyasu Abba Abdullahi

Contact details:
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Supervisor: Georgios Kapogiannis – Georgios.Kapogiannis@nottingham.edu.cn
University Research Ethics Committee Coordinator, Ms. Joanna Huang (Joanna.Huang@nottingham.edu.cn)

→

Project title — Managing Project Complexity: A study on the adoption of Digital Construction Strategy to improve performance on Mega Infrastructure Projects

Researcher's name: Iliyasu Abba Abdullahi

Supervisor's name: Georgios Kapogiannis

I have read the Participant Information Sheet, and the nature and purpose of the research project have been explained to me. I understand and agree to take part.

I understand the purpose of the research project and my involvement in it.

I understand that I may withdraw from the research project at any stage and that this will not affect my status now or in the future.

I understand that while information gained during the study may be published, I will not be identified, and my personal results will remain confidential.

I understand that the data collection *will be recorded.*

I understand that data will be stored in accordance with data protection laws.

I understand that I may contact the researcher or supervisor if I require more information about the research and that I may contact the Research Ethics Sub-Committee of the University of Nottingham, Ningbo, if I wish to make a complaint related to my involvement in the research.

Keywords description

Digital construction strategy integrates two or more technological tools to redefine how people carry out construction operations in a safer, efficient, and collaborative manner to achieve better outcomes at each stage of the project lifecycle.

Competence is inherent capabilities that an individual brings to a project to influence overall performance.

Mega infrastructure projects are construction projects that command a considerably huge budget in contrast to national GDP, which in most instances cost over a billion US dollars. This project could be in transport infrastructure, utility construction, or large building construction.

Complexity is the characteristics of a project triggered by elements of difficulty and uncertainty, causing wanton challenges during the project.

I consent to participate

I decline my participation

Your professional affiliation is ______________

- Architect
- Builder
- **Civil Engineer**
- Planner
- Project Management
- Quantity Surveying

Years of field experience

- Less than 5 years
- Between 5 and 10 years
- Between 10 and 20 years
- More than 20 years

Your highest level of formal education attained

- Diploma
- BSc/HND
- MSc
- PhD

Nature of infrastructure development you mainly participate in. You can select multiple options

- Building infrastructure (i.e., hospital, airports, etc.)
- Chemical plants construction (i.e., refinery, fertilizer plants)
- Rail network construction
- Road network construction
- Utility facilities (i.e., dams, power station, water treatment plant

What region do you practice

- Africa
- Asia
- Europe
- Middle East
- North America
- Oceania
- South America

→

Instruction: When completing this section, imagine yourself on a construction site, developing a large and complex infrastructure project, and answer from a general perspective. Your thoughts should not only be limited to the projects you were involved in while determining the extent to which you agree or disagree that digital construction influences the project manager's competence during infrastructure construction from the questions below. **Your choice should range from 0 - very strongly disagree to 6 - very strongly agree**

Communication is pivotal for project managers to interact and provide project information to the project and its people effectively during construction. Please indicate to what extent you agree or disagree that adopting digital construction supports managers to perform the following roles during construction effectively. **Your choice should range from 0 - very strongly disagree to 6 - very strongly agree**

	0	1	2	3	4	5	6
Provide a suitable communication mechanism to interact with the numerous project participants concurrently	○	○	○	○	○	○	○
Proffer an appropriate communication system to interact with participants on multiple project sites actively.	○	○	○	○	○	○	○
Ensure a communication channel that fosters timely response on-site during construction.	○	○	○	○	○	○	○
Supports managers with a reporting system to transmit project specification changes effortlessly.	○	○	○	○	○	○	○
Provides managers with a robust feedback system to transmit accurate instructions from the numerous project drawings	○	○	○	○	○	○	○
Enable managers to distribute timely instructions to disperse project teams	○	○	○	○	○	○	○

Planning enables managers to appropriately schedule and allot project resources to ensure optimal performance during construction. Please indicate your level of agreement or disagreement that employing digital construction support project managers to effectively plan project resources during mega infrastructure construction from the following construct. **Your choice should range from 0 - very strongly disagree to 6 - very strongly agree**

	0	1	2	3	4	5	6
Explore different planning approach to manage sequence rigidity during construction	○	○	○	○	○	○	○
Breakdown the project scope into more workable components	○	○	○	○	○	○	○
Easily schedule workers irrespective of the project site's overall size	○	○	○	○	○	○	○
Forecast resources required during construction by accurately estimating the budget	○	○	○	○	○	○	○
Ensure workers are effectively utilized despite the numerous workers on-site	○	○	○	○	○	○	○
Enable efficient distribution of material usage on multiple locations during construction	○	○	○	○	○	○	○
Create measures that ensure adequate time utilization amidst high project tempo	○	○	○	○	○	○	○
Implement measures to achieve defined quality objectives when using unfamiliar construction methods	○	○	○	○	○	○	○
Provides a platform to monitor the project's vast supply chain	○	○	○	○	○	○	○

Information management covers how information is collated, recorded, reported, and used for project control purposes. Please indicate the extent to which you agree or disagree that digital construction could enable project managers to perform the following during infrastructure construction. **Your choice should range from 0 - very strongly disagree to 6 - very strongly agree**

	0	1	2	3	4	5	6
Collect project information to estimate time and budget accurately	○	○	○	○	○	○	○
Provides a common data environment as a holistic medium to distribute project specification changes to subcontractors concurrently	○	○	○	○	○	○	○
Gather real-time information on construction challenges from the numerous project team on-site	○	○	○	○	○	○	○
Accurately store project information changes over a more extended project duration	○	○	○	○	○	○	○
Make project information accessible from multiple site location to resolve any request for information (RFIs)	○	○	○	○	○	○	○
Ensures redundant information is prevented from the numerous information source	○	○	○	○	○	○	○

Problem-solving entails defining, analysing, prioritising, and finding alternatives to solve challenges and complex construction problems. To what extent do you agree or disagree that adopting digital construction enables managers to perform the following roles during construction?

Your choice should range from 0 - very strongly disagree to 6 - very strongly agree

	0	1	2	3	4	5	6
Perceive potential problems that may occur from project specification changes	○	○	○	○	○	○	●
Gather relevant information from multiple site locations when a problem occurs	○	○	○	○	○	●	○
evaluate rigid work sequence to determine viable solutions to challenges from the site topography	○	○	○	○	○	●	○
Generate possible solutions to manage uncertainty effects from task difficulty.	○	○	○	○	○	●	○
Implement the most viable solution to curtail the negative impact of uncertainty stemming from untried construction methods	○	○	○	○	○	●	○
Evaluate the positive impact of the selected solutions in managing scope uncertainty	○	○	○	○	○	○	●

In the face of uncertainty, **decision-making** is the process of making logical choices by identifying a decision, gathering information, and assessing alternative decisions. Please indicate your level of agreement or disagreement to the extent that digital construction augments the project manager's competence to achieve the roles below. **Your choice should range from 0 - very strongly disagree to 6 - very strongly agree**

	0	1	2	3	4	5	6
Enable managers to analyse decisions from the viewpoint of the numerous project participants	○	○	○	○	○	○	○
Gather relevant information that supports decision framing in the face of unforeseen circumstances	○	○	○	○	○	○	○

Identify alternative decisions that could be adopted to manage project tempo	○	○	○	○	○	●	○
Decide based on the available information gathered from multiple locations on-site	○	○	○	○	○	●	○
Transmit decisions clearly to the entire project participants in real-time	○	○	○	○	○	○	●
Implement decisions on multiple locations to curtail the effects of uncertainty	○	○	○	○	○	○	●
Monitor the implication of the decisions taking in cognizance to the revised project baseline	○	○	○	○	○	○	●

Developing teams is training and mentoring team members to ensure they perform their job roles effectively. Please indicate the level you agree or disagree with that digital construction supports project managers to accomplish the functions below. **Your choice should range from 0 - very strongly disagree to 6 - very strongly agree**

	0	1	2	3	4	5	6
promote real-time training to develop the project team's capability on the unfamiliar construction method	○	○	○	○	○	○	○
Support managers to provide responsive leadership to the numerous workers om-site when faced with uncertainty	○	○	○	○	○	○	○
Visulise the project site topography to support workers' navigation on large construction sites	○	○	○	○	○	○	○

Identify alternative decisions that could be adopted to manage project tempo	○	○	○	○	○	●	○
Decide based on the available information gathered from multiple locations on-site	○	○	○	○	○	●	○
Transmit decisions clearly to the entire project participants in real-time	○	○	○	○	○	○	●
Implement decisions on multiple locations to curtail the effects of uncertainty	○	○	○	○	○	○	●
Monitor the implication of the decisions taking in cognizance to the revised project baseline	○	○	○	○	○	○	●

Developing teams is training and mentoring team members to ensure they perform their job roles effectively. Please indicate the level you agree or disagree with that digital construction supports project managers to accomplish the functions below. **Your choice should range from 0 - very strongly disagree to 6 - very strongly agree**

	0	1	2	3	4	5	6
promote real-time training to develop the project team's capability on the unfamiliar construction method	○	○	○	○	○	○	○
Support managers to provide responsive leadership to the numerous workers om-site when faced with uncertainty	○	○	○	○	○	○	○
Visulise the project site topography to support workers' navigation on large construction sites	○	○	○	○	○	○	○

Promote collaborative working amongst the numerous project team members	○	○	○	○	○	○	○
Designate every project member's work package despite the numerous participants on the project	○	○	○	○	○	○	○
Easily define every project members responsibility despite the enormous project scope	○	○	○	○	○	○	○
Provide an interface that supports trust-building with the numerous workers on-site	○	○	○	○	○	○	○

How frequently does your company rely on technological tools during project construction

- Always
- Frequently
- Sometimes
- Rarely
- Never

How comprehensive is your company's digital construction strategy

- Extremely comprehensive
- Substantially comprehensive
- Moderately comprehensive
- Partially comprehensive
- Not at all comprehensive

To what extent could the adoption of digital construction strategy potentially enhance project management competence during construction, from the list below. Consider a scale of **0 (not at all)** and **10 (significantly)**

0 1 2 3 4 5 5 6 7 8 9 10

Leadership

Planning

Directing

Effective decision-making

Communication

Supervising

Coordination

Motivates team

Issues and conflict resolution

Administering

Negotiation

Aptitude

Confidence and commitment

Proactive

Open-mindedness

Trustworthy

Analytical thinking

→

Appendix D (Descriptive Statistics)

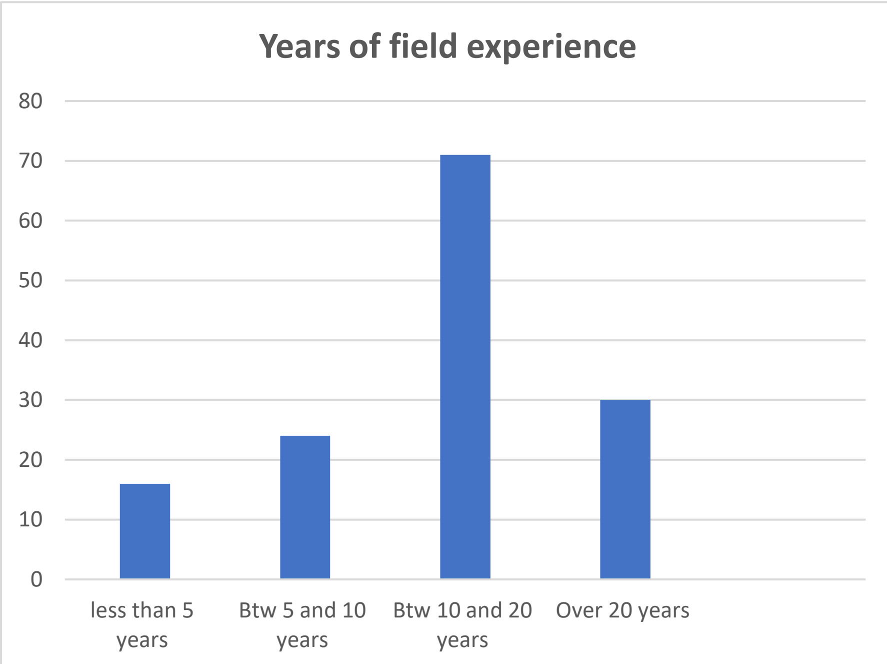

Figure showing sample's field experience.

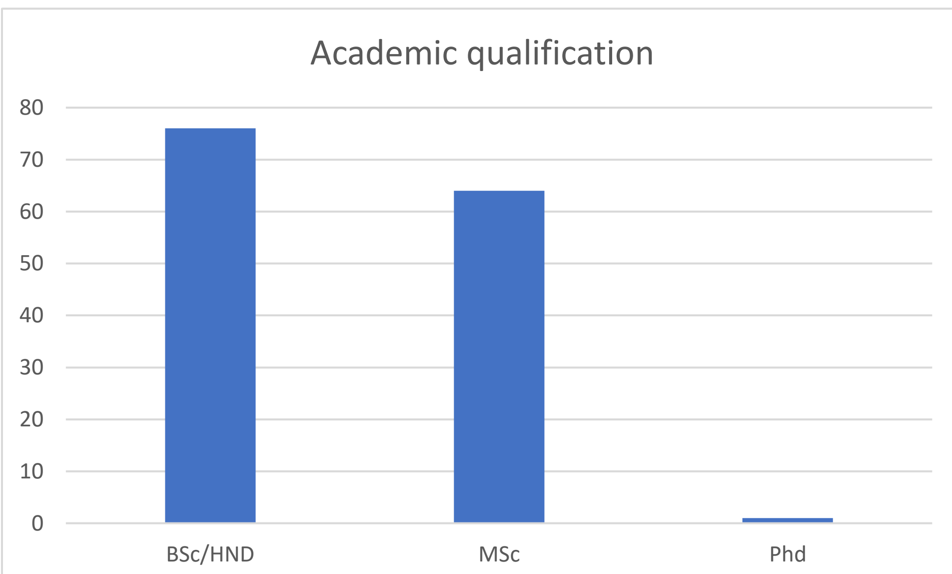

Figure depicting project managers academic qualification

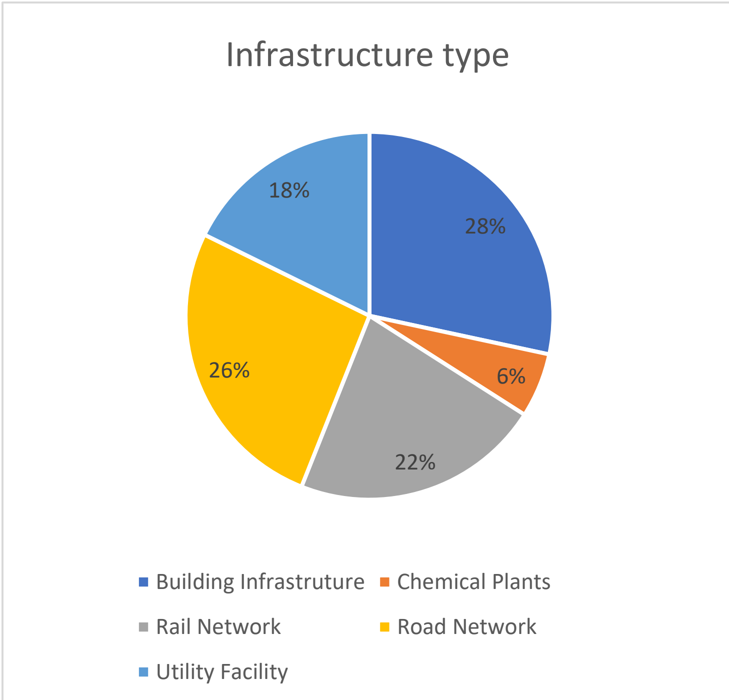

Figure showing the infrastructure type the sample have participated

Appendix E (Conceptual Framework Validation Questionnaire)

Section I: Demographic data
Position within your organisation
Responsibility
Years of experience
Any other information

Section II: Framework clarity	Ranking (1- Strongly disagree and 5 - strongly agree)				
To what extent do you agree with the assertion that	1	2	3	4	5
Clearly defines the key interrelationships.					
Clearly defines a strategy for competence development.					
Clearly defines a pathway for complexity management.					
Is relevant for actual construction practices					
Any other comment?					

Section III: Framework Applicability	Ranking (1- Strongly disagree and % - strongly agree)				
To what extent do you agree with the assertion that	1	2	3	4	5
The framework is easily comprehensible.					
The framework is easy to use					
The framework is relevant to competence development.					
The framework is relevant to complexity management practices.					
The framework supports construction management practices.					
Would you consider the proposed framework in your professional endeavour?					
Any other comment?					

- Do you have any recommendations for modifications or enhancements to the complexity management framework?
- Is this complexity management framework something you would consider utilising?