

**MODELLING THE IMPACT OF THE ADOPTION OF DIGITAL
TECHNOLOGIES ON PRODUCTIVITY IN THE SOUTH AFRICAN
CONSTRUCTION INDUSTRY**

by

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*This dissertation is submitted towards fulfilment of the requirements for the Degree of
Doctor of Philosophy (PhD) in Construction Economics and Management*



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ABSTRACT

An endemic problem across the South African construction industry is low project productivity. This challenge affects the profitability and sustainability of a construction project, stakeholders and investors across the industry, and the lifecycle of both the project and organisations, with financial implications. Other variables that affect project success include external factors such as environmental, organisational, and technical factors. The fragmentation of the construction industry is considered a fundamental contributing factor to this phenomenon. Studies suggested that the lack of digitalisation in the construction industry is a significant contributing factor to fragmentation and, subsequently, the prevalence of poor project productivity. This study focuses on how the adoption and implementation of digital technologies impact project productivity.

This study evaluates the types of digital tools used across the South African construction industry, the level of skill required among professionals, assesses how these tools mitigate the impacts of external factors, and determines barriers to the adoption of digital tools. The main research question this study investigated is: “*What relationship exists between the adoption of digitalization and the level of construction productivity in South Africa?*” The development of a conceptual framework for this study is based on the theoretical principles derived from Disruptive Innovation Theory, Configuration Theory, Chaos Theory, and Technology Adoption Model. The study adopted a mixed-methods research design, comprising both quantitative and qualitative approaches. Contractors listed on the cidb registry in the category Grade 4 – 9 were approached between May 2024 and December 2024. A total of 92 valid responses were obtained from 411 distributed questionnaires, which represents 22,38% response rate. The collected quantitative data were analysed using descriptive statistics, including frequencies, standard deviation, mean item score, relative importance index, and ranking. The testing of the research hypotheses was conducted using structural equation modelling, Spearman’s rho, and Kruskal-Wallis tests. The qualitative analysis of the study was conducted with eleven purposively selected construction professionals, including CEOs of digital software companies, quantity surveyors, project managers, civil engineers, and health and safety specialists. NVivo was used in the thematic analysis of the qualitative component of the data. The study's findings reveal a statistically significant relationship between the adoption of digital technologies and project productivity. The study reveals that reduced

planning periods, identifying risks from the outset, and reduced rework are core benefits of digitalising. Another finding of the study is that selecting digital tools that adapt to various external variables is important. The structural equation modelling revealed that there is no statistically significant relationship between adopting digitalisation and the impact of external variables. Strategic planning and the adoption of digital technologies depend on the size of the project and an organisation's willingness and knowledge of their use. Significant improvement in skills training among construction professionals is important to the progression of digital adoption. Furthermore, the study found that external variables, environmental, organisational, and technical factors have no significant impact on productivity when moderated by digitalisation, implying that selecting digital tools is not important in addressing the impact of external variables on productivity. Based on these findings, the study concludes that strategic planning and the adoption of digital technologies depend on project size and an organisation's willingness. Additionally, the study concludes that expertise and the size of an organisation affect the types of tools available to optimise productivity. The organisational objective is directly related to procurement strategies and the skills required to optimise digital tools. Lastly, there is minimal impact of external factors on digital adoption. The study recommends that significant improvements in skills training among construction professionals are important to the progression of digital adoption and improved productivity.

Keywords: Digitalisation, adoption of technology, project performance, innovation and productivity, construction industry, barriers, skill and knowledge, South Africa, 4IR.

DECLARATION

Name : **Mr Mochelo Mackson Lefoka**

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I know the meaning of plagiarism and declare that all the work in the document, save for the properly acknowledged, is my own. This dissertation has been submitted to Turnitin, and I confirm that my supervisor has seen my report and any concerns revealed by such have been resolved with my supervisor. I have not allowed and will not allow anyone to copy my work with the intention of passing it off as his or her own work.

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DEDICATION

This project is dedicated to every student I ever had the tremendous pleasure of teaching. Seeing all of you develop from curious to mastery and ultimately, to being the experts in your field has been the greatest pleasure of my life. Your dedication was evidenced by nothing but your commitment and sheer passion for the construction industry. Here is to another body of knowledge that contributes to our industry in a meaningful approach and shifts the landscape of our profession.

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LIST OF ABBREVIATIONS

AFP	Average Factor Productivity
AR	Augmented Reality
BIM	Building Information Modelling
BOQ	Bills of Quantities
CE	Civil Engineering
CIDB	Construction Industry Development Board
DT	Digital Technologies
EB	Electrical Engineering Works – Building
EF	environmental Factors
EP	Electrical Engineering Works – Civil
FIDIC	The international Federation of Consulting Engineers
GB	General Building
GBCSA	Green Building Council of South Africa
GDP	Gross Domestic Product
H&S	Health and Safety
EU	European Union
HT	Hard Technologies
IDC	The Industrial Development Corporation
ICT	Information and Communication Technology
IT	Innovative Technologies
JBCC	Joint Building Contracts Committee
DIT	Disruptive Innovation Theory
DTT	Digital Twin Towers
VR	Virtual Reality
LDCs	Least Developed Countries.
2D	Two Dimensional
3D	Three Dimension
4D	Four Dimensional
IoT	Internet of Things
WBS	Work Breakdown Structure

TFP	Total Factor Productivity
ME	Mechanical Engineering
NEC	New Engineering Contract
OC	Organisational or Construction
PFP	Partial Factor Productivity
PPE	Personal Protective Equipment
RFI	Request for Information
SDG	Sustainable Development Goals
SARS	South African Revenue Services
SPSS	Statistical Package for the Social Sciences
ST	Soft Technologies
TF	Technical Factors
UN	United Nations
UAVs	Unmanned Aerial Vehicles
VIF	Variable Inflation Factor

CHAPTER ONE

1.1 General Introduction

This chapter introduces the research topic, and keywords pertinent to this research. Additionally, the research question, the aim and objectives of the study are introduced, and the hypothesis is presented. Furthermore, a synopsis is presented of the background literature review, which was conducted as a preliminary introduction to the topic. A conceptual and theoretical framework is also introduced. The research methodology intended for this study is outlined, followed by the significance, limitations and the scope of the study.

1.2 Background to the study

1.2.1 General Background

The construction industry plays a significant role in the development of infrastructure, which is pertinent to the operation of other economic sectors globally (Kazaz and Ulubeyli, 2004; Alinaitwe *et al.*, 2005; Enshassi *et al.*, 2007; Baloyi and Bekker, 2011; Giang and Pheng, 2011; Green, 2015; Barbosa, Woetzel, Mischke, *et al.*, 2017). This places the construction industry amongst other contemporary industries in its contribution to the economy's Gross Domestic Product (GDP) (Barbosa, Woetzel, Mischke, *et al.*, 2017). This purports the assertion that the construction industry significantly impacts economic growth and acts as a vehicle to skills development across sectors (Ngubane *et al.*, 2023). However, according to StatsSA (2022), and StatsSA (2025), the level of unemployment in South Africa sits at 33,9%. This is indicative of the high levels of inequality in South Africa (StatsSA, 2022; Ngubane *et al.*, 2023). The industry's position in contributing to both the formal and informal sectors gave rise to the interrogation of the interconnectedness between digital technology adoption, readiness of the industry to adopt, as well as the impact on the levels of construction productivity (Petrov and Hakimov, 2019; Arsić, 2020; Shiha and Dorra, 2023).

A significant subset of the construction industry largely relies on human capital (Okorafor *et al.*, 2016). Various scholars note that it is imperative to interrogate the relationship between

the integration of digital technologies and human capital responsible for the actualisation of construction projects (Soekiman *et al.*, 2011). Additionally, this is due to the 40% contribution of the labour cost on South African projects (Tran and Nguyen, 2024). This argument is expanded further by Durdyev and Mbachu (2011) in positing that prior to the integration of human capital with digital technologies, the labour component needed training in the various technologies. Additionally, a gradual and systematic integration of these digital technologies is imperative in order to mitigate the disruption of the construction process which impact construction productivity (Durdyev and Mbachu, 2011; Berlak *et al.*, 2021). As much as the global shift has been towards the adoption and, in some cases, the mandate that the construction industry should have some form (or in part) a great percentage of work digitalised, it points to the issue of the capacity to do so (Schober *et al.*, 2016). In order to understand the expend of digital adoption and its meaning, it is imperative to elaborate further on what constitute construction productivity.

Lema (1996) describes construction productivity as the adoption of a process through the preparatory stages of a project, with the identification of inputs to be used through a process of the construction project to yield the desired output. It is further stated that this description encapsulates the preparation of inputs, the actual inputs, the process of conversion (processes) and the output as can be easily mapped to different construction outputs/projects (Lema, 1996). A further expansion of this description is drawn by Rathnayake and Middleton (2023) in positing that in a refined sense, productivity is the output per unit of input. However, Park (2006) argues that it is difficult to establish a universally accepted definition of construction productivity because each construction company operates within its own internal systems and defines productivity according to the specific requirements, objectives, and desired outcomes of its projects. Although productivity can be simplistically expressed as the ratio of output over input, other scholars (Makulsawatudom *et al.*, 2004; Enshassi *et al.*, 2007; Yi and Chan, 2014) argue that this definition is limiting as a lot of factors are included in the input and as a result, specificity is required in deducing productivity for a study. As a result, this study adopts Park (2006)'s definition of construction productivity.

According Aleksandrova *et al.* (2022), digitalisation is defined differently by various scholars and industries, depending on the operational function and type of technology utilised. Gray and Rumpe (2015) defines digitalisation as the integration of multiple technologies through phases

of a project life cycle, in the utility and application of the said technologies for improved productivity. However, Berger (2016) defines digitalisation as the utilisation of technological tools and systems that are dependent on the information and communication pathways of selected technological tools for optimal productivity and project performance. In addition to Berger (2016)'s definition, scholars expand this in positing that changing and altering the business models to provide new revenue, increased output, and value-producing benefits, are key to the definition of digitalisation (Gray and Rumpe, 2015; Castagnino *et al.*, 2016; Çıdık and Thurairajah, 2017; Freddi, 2018; Madanayake and Cidik, 2019). The definition introduced by Berger (2016) is to be adopted for this study. It further follows that the two types of digitalisation frameworks are distinct, yet interdependent, as they rely on one another for data distribution, analysis, and the generation of the outputs required for effective functioning. It is imperative to understand the symbiotic relationship that exists between what literature terms “hardware-based” (hard-technologies) and “software-based” (soft-technologies) digital frameworks. Hard technologies are referred to as physical machinery and robotic systems that operate and do the work of bringing a structure together. These also include the setting out and surveying robots and scanner machines. Examples of these are production robots, 3D printing machines, surveying and scanning drones, virtual reality (VR) simulation labs and modular construction facilities in assembling structures (Berlak *et al.*, 2021; Siddiqui, 2022). Soft technologies refer to computer-generated coding and sequencing interfaces which collect large datasets. These are aided by operating directive dispensing mechanisms to control, manage and regulate the operation of hard technologies. This is done either remotely from the development or construction site (Siddiqui, 2022). These digital technologies include BIM software, predictive analytics, big data and Internet of Things (IoT) (IDC, 2020).

1.2.2 General Background – Digital Application

According to Ifeoma, *et al.* (2021), digitalisation is considered the main applicable method of improving productivity in the construction industry. A review of the global literature on construction productivity reveals a synthesis of the key factors contributing to poor productivity. These factors have been identified by various scholars from both developed and developing countries, offering a broad perspective on the underlying causes of productivity challenges within the construction industry. Barbosa, Woetzel, Mischke, *et al.* (2017) assert that at the centre of a construction development, the fragmented nature of the design process

and minimal investment observed across construction firms, gives rise to the poor productivity of the projects. Furthermore Barbosa, Woetzel, Mischke, *et al.* (2017) posited that the underinvestment in digital technologies and innovative construction methods by both government enterprises as well as the construction industry as a whole impacts the productivity on projects.

Notwithstanding that, at the core of digitalisation is the insufficiency of the skills to operate these digital systems and understand their function. This is argued to be observed across frontline workers on construction projects lacking skills, training and knowledge (Barbosa, Woetzel, Mischke, *et al.*, 2017). According to Smidt and Jokonya (2022), this assertion is prevalent in the advent of adopting new digital tools given that it is only recently being adopted in the construction industry. There is currently no strong empirical evidence demonstrating the overall benefits of digitalisation in the construction industry. However, other industries have shown that digitalisation can successfully improve productivity and operational efficiency. Since similar results have not yet been clearly demonstrated in construction, it is reasonable to infer that the industry could also benefit from digitalisation. As a result, this assumption still needs to be tested and validated within the construction context (Enshassi *et al.*, 2007; Barbosa, Woetzel, Mischke, *et al.*, 2017; Cidik, 2019).

The adoption of varying digital technologies, such as BIM software, robotics, and cost management tools, is integral to most construction projects (Ibem and Laryea, 2014; Schober *et al.*, 2016; van Wyk *et al.*, 2024a). The digitalisation of construction processes has become integral to the modern methods of project development. This has transformed the construction industry into an integrated and systematically operated industry (Schober *et al.*, 2016; Petrov and Hakimov, 2019). The adoption of these tools has improved project profitability and productivity, while also reducing risk and design errors. Digitalisation therefore serves as a means to control and monitor the construction process (Petrov and Hakimov, 2019). Literature indicates that low productivity levels are driven by a range of interrelated factors, including regulatory and legislative constraints, broader external influences (such as social, environmental, and organisational conditions), and deficits in education and skills development (Durdyev and Hosseini, 2020; Argyroudis *et al.*, 2022; Sanni-Anibire *et al.*, 2022). A similarity about these factors is that they are endemic to the construction industry (Barbosa, Woetzel, Mischke, *et al.*, 2017). Notwithstanding that, Osunsanmi *et al.* (2018) contends that the

influence of these factors is context-dependent, varying across different countries, project typologies, and project scales. Nevertheless, empirical observations suggest a consistent pattern: when these factors are present, they predominantly exert a unidirectional effect, contributing to increases in either project costs, project duration, or both, thereby underscoring their role as systematic drivers of project overruns across diverse settings (Olawale and Sun, 2010; Simushi and Wium, 2020).

Barbosa, Woetzel and Mischke (2017) posits that in the past fifteen years, the levels of productivity across the global economies have presented a decline. Amidst this assertion, the advocacy of digitalising is presented as a resolve. However, specific relationship coexisting between productivity and actual digital digitalisation was established. Aliu and Oke (2023) draws the focus on inhibitors of digitising within the construction industry. A synthesis of the relationship between the use of digital tools and the inability to use them shows that it is influenced by technical, environmental, and social factors. However, the relationship between increased levels of productivity and the tools adopted remains underdeveloped. Aliu and Oke (2023), however, broadens Chen *et al.* (2024) landscape of discussion in poignantly establishing the benefits of digitising and the findings suggested an increase in construction productivity. Aliu and Oke (2023) The study did not incorporate external factors in its evaluation, nor did it synthesise how digitalisation may mitigate the influence of externalities beyond the control of project stakeholders. To properly understand the relationships under investigation, it is necessary to first examine the contextual benefits and constraints specific to South Africa.

1.2.3 General Background – South African Challenges with digital application

The South African construction industry has slowly been adopting digitising especially through the use of BIM for project planning and management functions of a project (Akinradewo *et al.*, 2024; van Wyk *et al.*, 2024a). However, the skill and knowledge necessary to do so, hinder the pre-empted assumption that digitising can improve productivity and construction processes (Emmanuel *et al.*, 2018; Ikuabe *et al.*, 2020; Akinradewo *et al.*, 2024). A strong point of contention concerning this impediment is that the extent of its impact across other forms of technologies has not been studied, and thus generalisability cannot be drawn from this limitation to full adoption of digital systems (Aghimien *et al.*, 2018b). A similar pattern is observed when examining construction workers' willingness and its relationship to

productivity, and Wang *et al.* (2019) concluded that China showed the same trend. A contradictory observation is noted in countries such as New Zealand and Germany. They report that the understanding and knowledge of what digital skills are needed is what is utilised to advance productivity and adoption of digital tools in the construction industry (Chowdhury *et al.*, 2019; IDC, 2020; Siddiqui, 2022). Moreover, this adoption across projects suggests that the implementation of digitisation positively affects construction productivity (Chen *et al.*, 2022; Aliu and Oke, 2023). This improvement is primarily observed in the successful management practices and project performance, better control of the construction scheduling, minimisation of the project cost and time, as well as the reduction of waste on the construction project (IDC, 2020; Berlak *et al.*, 2021). However, this argument holds true for countries that are on the cutting edge of new developments of technologies, have lower unemployment rates and have significant government support, such as Europe, Netherlands, Denmark, Finland, Norway, Germany and France (Berger, 2016; IDC, 2020; Ribeirinho *et al.*, 2020).

According to the objectives in the National Digital and Future Skills Strategy of South Africa, signed by the Minister of Communications and Digital Technologies in August 2020, it is expressly stated that South Africa and the various industries are encouraged to streamline the processes and operations of their organisations to digital methods (Africa, 2020; Berlak *et al.*, 2021). The fundamental obstacle which is central to the strategy is the lack of adequate skillset and training, as well as the lack of knowledge of how to utilise digital technologies in advancing the mandate for improved productivity (Chen *et al.*, 2024). This is congruent with the problems like those mentioned, that the international scholars of digitalisation and innovative technologies are reporting (Berger, 2016; IDC, 2020; Papadonikolaki *et al.*, 2020). This further highlights gaps that are reported in the construction industry, which prevent projects from meeting time, cost and quality objectives (Ofori *et al.*, 1996b; Chen *et al.*, 2022). There is also stagnation in the construction industry when assessing it from the point of growth, in terms of construction productivity and project success, in relation to the adoption of digitalisation technologies (Aghimien *et al.*, 2018a; Cidik, 2019). These are the engineering phases (design), construction and operation phases (Castagnino *et al.*, 2016). Furthermore, Castagnino *et al.* (2016) posited that the application of digitalisation technologies in these life-cycle phases allows the elimination/reduction of construction uncertainty and contributes to poor productivity (Adeniyi *et al.*, 2024). The focus of this research is on the construction phase, where the open construction environment is susceptible to external factors, and this is where

digitalisation technologies are used.

According to Madanayake and Cidik (2019), there are considerable variances in exploring other forms of digital tools a control and management model on a construction project, in some parts of construction development, particularly the planning and the design phase, and especially when using Building Information Modelling (BIM), Virtual Reality (VR), 3D printing, robotics, blockchain and big data (Barlish and Sullivan, 2012; Wang *et al.*, 2020; Chen *et al.*, 2022; Siddiqui *et al.*, 2023). Digitalisation and innovative technologies have largely been esteemed as the main drivers in the improvement and increase of construction productivity globally (Berlak *et al.*, 2021). Additionally, the investigation of the adoption of digitalisation and the performance of construction projects is significant for the design and execution phase of a project (Schober *et al.*, 2016; Berlak *et al.*, 2021). Central to this inquiry about the adoption of digitalisation is that these digital technologies aid in the visualisation and precision of the dimensions of the varying drawings (structures) as well as the integrated network that allows the design team to accurately design structures that eliminate latent issues that may ensue during the design stage (Sui Pheng *et al.*, 2019). It is purported that this integral function contributes to eradication of errors in designs (Wang *et al.*, 2020), time reduction across disciplines when information is required (Akinradewo *et al.*, 2024) and these benefits, contribute to optimal productivity. This further supports the project to remain within cost and time constraints (Ibem and Laryea, 2014). Juxtaposed to the documented benefits of digitisation, are barriers which hampers both the pace and integration of measuring expected productivity through these digital tools.

A large part of construction project development is the reliance on the accuracy of the project data, the impact of the geographical and economic facts, as well as the proficiency of the management team to oversee the construction business (Park, 2006; Durdyev and Mbachu, 2011). Literature identifies factors that impact the construction business. These factors are causal variables to the prediction of the expected construction productivity, organisation and management of the site activities and determinants of an emergence in cost and time overruns (Jarkas and Bitar, 2012). The common categorisation of these factors is environmental, management, social, and technical (Olomolaiye *et al.*, 1987; Kaming *et al.*, 1998; Makulsawatudom *et al.*, 2004; Baloyi and Bekker, 2011; Durdyev and Mbachu, 2011; Hughes and Thorpe, 2014; Jarkas, 2015; Hiyassat *et al.*, 2016). The lack of standardised matrices of

measuring construction productivity presents a complexity in the event that project process is impacted by these factors (Lopes, 1998). According to Kazaz and Ulubeyli (2004), This lack in standard measures presents an even more complicated phenomenon on both the construction project and organisation when projects are differentiated by geographical location, utility of the project and the type of project. This further exacerbates the degree of impact fragmentation presents (Lam *et al.*, 2001; Kazaz and Ulubeyli, 2004). However, according to Verhoogen (2023), industrialisation has significantly contributed to digitising, and as a result, the adoption of digital tools. A further expansion of this assertion is that philosophies and principles used in industrialisation have the same capabilities to improve productivity in the construction industry, across various projects (Verhoogen, 2023). Sui Pheng *et al.* (2019) refutes this hypothesis by drawing parallels between a monolithic production of a singular type of output to the complexity of a construction project and additionally, positing that the immobility of construction projects further exacerbates the impact of external factors, particularly from the perspective of cost incurred in the event of plant and equipment damage, idle time and probable shutdowns of projects due to external factors (Enshassi *et al.*, 2007; Barbosa, Woetzel, Mischke, *et al.*, 2017). Substantial levels of labour productivity decline have been recorded, and over the past two decades, the levels have evidenced close to negligible levels of improvement or increase (Barbosa, Woetzel, Mischke, *et al.*, 2017).

Legislative and policy inflexibility is cited amongst other forms of barriers to digitise. Across global construction organisations surveyed, 93% agreed to the prospect of improved productivity if that were the case (Berger, 2016). However, 6% of the studied organisations used some kind of digital tool, and most of these were software packages for blockchain, BIM and cost management software (Berger, 2016; Wang *et al.*, 2020). It is posited that across developed countries, early adoption aided in this adoption (Arabshahi *et al.*, 2021). However, this is not the case in the South Africa construction industry as the lack of education pertinent to digital technologies such as BIM software, was not there and this delayed the adoption (Akinradewo *et al.*, 2024). Furthermore, factors such as accessibility, lack of investment in digital infrastructure and fragmentation of construction industry contributes significantly to the slow adoption across South African construction industry (Berger, 2016; Ribeirinho *et al.*, 2020; Berlak *et al.*, 2021; Siddiqui, 2022). According to Heymann *et al.* (2018), European Union (EU) directive mandates that for the awarding of a government contract, an organisation should have digital utility in their construction processes. In 2015, the German Federal Ministry

of Transport and Digital infrastructure established the multiphase digital planning and construction in Germany in order to digitise the construction industry (Berger, 2016; Heymann *et al.*, 2018; Werner and Lehan, 2023). Another barrier which affects the adoption in South Africa is the lack of awareness regarding capabilities of digital technologies (Akinradewo *et al.*, 2024). A significant form of reluctance from top management and organisations to adopt technologies is cited as another barrier. Furthermore, concerns regarding data management and threats of cybersecurity impedes the willingness to digitise. According to Omari *et al.* (2023), financial investment, which is observed through the procurement processes in the acquisition of digital tools, dissuade the adoption across the industry. This is observed significantly across organisations which are still new in the construction industry, and in South Africa these are organisations below Grade 4 on the ROC (cidb, 2022; Rakgoale *et al.*, 2024). A fundamental barrier posited by Alwashah *et al.* (2024) is the low levels of investment in research and development of digital tools and their functionality. This impediment reinforced the development and initiation of this research; thus, it is a significant factor through which this study is anchored. These barriers are considered congruent with those experienced by the construction industry in other countries. However, for the purpose of this study, these are contextualised through the South African viewpoint and anchored in the theories used to formulate the conceptual framework for this study.

As digitalisation is the current mode of operation across industries, more studies advocate for its implementation (Berger, 2016; IDC, 2020). Yet there are only a few studies interrogating the effects on the current construction productivity and project performance. Additionally, limited studies give measures of how digitalisation impacts and affects labour productivity. Thus, the study aims to examine the impact of digitalisation with regards to selected technology systems (methods) with regard to skill, practical measures of labour productivity, and the integration of external factors impacting the complex and dynamic construction development process, to develop a framework that can be implemented. The aim is to design and select digital technologies that do not threaten but rather enhance construction productivity.

1.3 Problem statement

The construction industry has reported poor project performance, as evidenced by declining or low construction productivity. For over two decades, a major contributing factor to the poor

performance of construction projects has been the lack of skills and knowledge, and the industry's inability to integrate digitalisation/innovative technologies in its operations. Further fundamental factors contributing to low construction productivity include technical, social, managerial, and environmental factors. Globally, the literature postulates that there has been a gradual migration of traditional construction processes, such as the design stage, which integrate the sharing of information and knowledge through digital platforms such as BIM, IoT, VR, and predictive analytics, to achieve better design outputs. Additionally, the utilisation of drones, robotics, and 3D printing is among the fundamental hardware (hard technologies) used in the construction industry to increase productivity. Furthermore, government ministries responsible for infrastructure development have undertaken legislative measures to ensure that, for a complete migration of construction processes to digitalised modes, the awarding of contracts requires that at least half of construction production be fully digitalised.

These concerted efforts, championed by stakeholders worldwide, are plausible and actively demonstrate a commitment to transforming the construction industry to reflect the current digital surge. Furthermore, the utilisation of these technologies and new construction methods is cited to have evidenced positive improvement in the enhancement of construction productivity. However, there is a dearth of research on construction developments that have fully digitalised their operations, or done so in part, and on the effect the adoption of these technologies has had on construction productivity. In South Africa, the adoption of digital technologies within the construction sector remains limited, and empirical studies critically examining their impact on construction productivity, particularly with a focus on large construction firms, are relatively scarce. Furthermore, examining these digital technologies within the same ambit of external factors inclusion. It is at this point that this study aims to evaluate and analyse the assertion that the utilisation of digital technologies improves construction productivity and mitigates the impacts of external factors. Additionally, the study aims to evaluate capacity and to interrogate the skill set and knowledge required for the adoption of digitalisation/innovative technologies in the construction industry. The answer to this problem is significant because it will allow key role players in the construction industry to understand the scope of work and identify which digital technologies to employ on construction projects, based on the capacity, knowledge, and data accessibility available for decision-making. The main answer to this question is to indicate the relationship between construction productivity and the implementation of a specific technological tool.

1.4 Research question

The main research question for this study is structured as follows:

“What relationship exists between the adoption of digitalization and the level of construction productivity in South Africa?”

To address the main research question, answers to the following subset of questions are pertinent. The subset of questions is stated as follows:

RQ1: Which digitalisation techniques and innovative technologies are adopted and implemented on construction projects?

RQ2: What formulation and quantifiable variable are used to measure construction productivity on a specific construction project/development?

RQ3: What levels of skill, knowledge, and experience are needed across stakeholders in the adoption and implementation of a specific digitalisation technique?

RQ4: What relationship is observed between the adoption and implementation of digital technology/tools and construction productivity?

RQ5: Is there a relationship between external factors and construction productivity when digitalisation is introduced as a moderator?

RQ6: Is there a digitalisation strategy incorporating external factors and mitigation of barriers for optimal construction productivity?

1.5 Research aim

The aim of the research is to develop models to examine the impact of adopting digital technologies on construction productivity in South Africa, with a view to enhancing project delivery.

1.6 Research objectives

- a) Identify and assess the digital technologies adopted and implemented by construction organisations in South Africa.
- b) Determine the levels of skills, knowledge, and experience required of stakeholders in the use of digital technologies on construction projects.

- c) Establish the productivity standards of construction organisations on key aspects of construction projects.
- d) Establish the impact of the digital technologies adopted on construction productivity.
- e) Evaluate the gap in productivity between the traditional approach and the adoption of digital technologies.
- f) Formulate models for assessing the impacts of adopted digital technologies on construction productivity.

1.7 Research hypotheses

The hypotheses for this study are stated as follows:

H1: There is a significant relationship between digitalisation techniques (innovative technology) and the level of construction productivity on projects.

H2: There is a significant relationship between external factors and adoption-willingness for construction organisations to implement digital technologies.

H3: The relationship between skills (knowledge of digitalisation technology/innovative technology) and construction project productivity is moderated by training and adoption of digitalisation technologies (innovative technologies) on projects.

1.8 Significance of the study

In the past two decades, the construction industry has experienced significant declines in the levels of construction productivity across projects (Barbosa, Woetzel, Mischke, *et al.*, 2017). The contention across scholars is that this is due to poor workmanship (Okorafor *et al.*, 2016), lack of skill and economic changes and fluctuations in economic dynamics (Durdyev and Mbachu, 2011; Berlak *et al.*, 2021; Demirkesen and Tezel, 2022). However, a consensus amongst scholars is that the lack of digital adoption in the construction industry is the primary cause. Notwithstanding that, empirical evidence which supports this claim is perceived to be limited (van Wyk *et al.*, 2024a). There is an argument that this is the case due to the unclear definition of what constitutes productivity across construction projects (Park, 2006). The complexity of digital adoption and applications is considered part of the main cause of the decline in the levels of construction productivity (Smidt and Jokonya, 2022). On a micro level, it has been shown that external factors such as environmental, technical and organisational factors contribute to the larger discourse across the decline of productivity (Olomolaiye *et al.*,

1987; Kaming *et al.*, 1998; Makulsawatudom *et al.*, 2004; Baloyi and Bekker, 2011; Durdyev and Mbachu, 2011; Hughes and Thorpe, 2014; Jarkas, 2015; Hiyassat *et al.*, 2016). However, with the introduction of digitalisation as a disruptor in the construction industry, an evaluation of the relationship is explored. In comparison to other sectors such as the biomedical, banking, manufacturing and agriculture, digitalisation has evidenced tangible and measurable productivity output, which is not the case for the construction industry. This lack of direct correlation and quantifiable measures of how digitising the industry precludes the significance of the study.

Security and legislative compliance are complex policy concerns pertaining to digitisation as there are not stringent handling and management of data across planners, designers and construction managers (Smidt and Jokonya, 2022; Omari *et al.*, 2023). Additionally, the design of a legislative framework applicable across the industry with regards to the adoption. The findings of this study will facilitate the need for data protection across the digital platforms used to collect transfer and analyse pertinent data to the project. This will be facilitated by the construction contracts used in the industry to apportion time and resources, accurately safeguard against duplication of work done during the design phase, and streamline the remuneration of independent contractors who primarily design and commission the plans. These are the two focal areas that the findings of this study will do.

Significant research has been conducted on a singular form of digital tool in South Africa which is BIM, drones and 3D Printing projects (Barlish and Sullivan, 2012; Wang *et al.*, 2020; Chen *et al.*, 2022; Siddiqui *et al.*, 2023). However, there is a dearth of literature that discusses the process involved in acquiring digital skills and the required levels of competency to use and maintain such resources. Since this study allowed the respondents to express tools which they were familiar with, the findings of this study will be used across construction organisations when choosing a digital tool. The findings will allow organisations that are below the populous selected to evaluate the benefits of digitising, as well as the financial implications across defined levels of construction productivity. For organisations that are in the targeted population, the results of this study will provide a guideline of where to best invest time and capital across the lifecycle of a project, as this inadvertently affords them an expansive array of what projects they can execute concurrently, and which they need to stagger. Moreover, the integration of external factors across digital use will allow organisations to accurately choose

digital tools that are able to circumvent the effect of external factors, especially given the phase of the project under construction at a time.

In the advent of digitalisation, this study will be significantly beneficial to construction stakeholders (cidb) with regard to developing a strategic organisational registration matrix. It is prevalent across literature that the qualification of an organisation is primarily based on the work they are capable of doing, within a certain financial category (cidb, 2022). Not negating this, the proficiency in the work they are capable of executing must be monitored annually and with digital analytics. This is pertinent for the eradication of project abscondment and overstating costs during tendering. In other instances, minimising the cost of a project to later claim under VOs. Additionally, these findings will allow organisations to restructure their human labour component with recruits capable of doing the work and only need the practical training component to fully integrate in the industry. These findings contribute to significantly addressing the perception that digitising replaces jobs, as it evidences the need and efficacy of supplementing digital skills to the traditional operations in the industry. This will be evidenced in reskilling, retraining and exposure of the current operational systems in a constrained time and minimal wastage of cost. This can be placed under the ambit of retraining and gradual phasing-in of technology through either an organisational intranet or discussed through the recruitment process. The National Digital and Skills Strategy of South Africa was gazetted in August 2020, and to date, there is no evidence from higher learning institutions or high school level of its efficacy. A poignant finding of this study will aid in monitoring and assess the phasing in of this strategy across learning institutions. The findings can be used in curriculum review committees across learning institutions or across government stakeholders, directly involved with the critical aspects of developing and upgrading the curricula.

The predominant forms of digital technology are software packages, with the exceptions of drones, wearables, tablets and VR labs (Marks and Thomas, 2022). The feasibility standards in the selection of technology to use on projects will be significantly aided by the findings. This ensures that organisations that have the capability and knowledge will understand the use, maintenance and reprogramming of the selected technologies. This further assists in ensuring that the procurement of equipment which is costly and not user-friendly is eradicated. Moreover, the fact that this can be both a cost wastage and a deterrent to investment in the organisation.

1.9 Overview of research methodology

In the approach to identify the appropriate research methodology, an extant literature review was conducted. Keywords such as Digitalisation, adoption of technology, project performance, innovation and productivity, construction industry, barriers, skill and knowledge, South Africa, 4IR, were used to collect relevant literature. The collected literature was thematically sorted using NVivo 15 software package. Additionally, the collected literature was linked to an EndNote library and sorted according to the same themes.

The research philosophy that this study adopted was the positivist philosophy. The selection of this philosophy was based on its scientific merits, which are embedded in the capacity to deduce meaning from the analysed quantitative component of the research data (Skinner, 1956; Keeves, 1997; Leedy and Ormrod, 2005; Kivunja and Kuyini, 2017; Žukauskas *et al.*, 2018). This study is positioned within an industry with various levels of financial and project scope capacity, which are further differentiated by geographical location (cidb, 2022). This philosophy provides a uniform aggregation of data to draw generalisable meaning which provides insight into the operations of the construction industry (Creswell and Clark, 2017b). The study used a convergent mixed-method approach, which comprised both quantitative and qualitative in the data collection. The utilisation of the mixed-method approach afforded the study a depth of data across multiple disciplines, which through the deductive method, was able to assess the qualitative data using statistical tools and thematically analyse the qualitative data. This afforded the study an expansive analysis of data which generalisability can be drawn (Gephart, 2004; Farnad and Pouya, 2013; Creswell and Clark, 2017b).

The development of the research instrument for this study, was done in two phases. The first phase was the design of the questionnaire and interview questions. This was achieved by a second iteration of literature review and consultation with the supervisor in order to ascertain the rigour and appropriateness of the questions. Moreover, this was to align the instrument with the research objectives. The second phase was the piloting of both the questionnaire and the interview questions to ensure validity, reliability and complexity with regard to time. The questionnaire was administered to Grade 4-9 cidb ROC through the Survey Monkey platform. A set of interviews were set up with randomly selected professionals who also appear on the ROC or affiliated to the construction industry. Both these approaches were to ascertain that

exposure, adoption and implementation of digital technologies in the construction industry are assessed across parties that are critical to the construction project endeavour. Moreover, this was to extract necessary data which aligns with the objective to understand the degree of adoption and the precepts of barriers. Furthermore, demographic data, organisational data and levels of exposure were some of the necessary components retrieved from the participants.

Quantitative data was analysed using descriptive and inferential statistics. This included frequencies, Mean Item Score (MIS), Relative Importance Index (RII), standard deviations, and ranking. The testing of the research hypotheses was achieved through the use of IBM Statistical Package for the Social Sciences (SPSS) and the partial least squares structural equation (PLS-SEM 4). The use of both these packages provides a regression and correlation analysis which aided in the observation of the kind of relationship that exists across constructs, the strength and direction of the relationship, as well as the strength of the relationship/correlation. Due to the variables that this study was analysing, these tools were able to aggregate an analysis of large data also provide the kind of distribution observed across the construction organisations.

Qualitative data was analysed through the use of NVivo 15 software package. The software package was able to categorise the collected data into themes which were later analysed to draw conclusion.

1.10 Scope of the study

The scope of the study is primarily focused on construction firms/companies that have integrated into their operations some form of digitalisation technologies into their operations. Moreover, companies that have a grading of 4-9 on the cidb register of contractors (ROC) in South Africa. It is observed that companies in this categorisation are considered to have resources and influence over the construction industry as they have established more specialised divisions (cidb, 2022). The specific people that the study aims to get information from are the users of digitalisation technologies/innovative technologies on construction projects.

1.11 Limitations of the study

The study is subject to three limitations, which have also been observed through the literature review as contributing largely to the adoption of digitalization on construction projects. One of the limitations is that with the slow adoption of digitalization across the construction industry, some firms may only use soft technologies such as Building Information Modelling (BIM), MS Projects, and handheld devices. These are not mechanised robotics, robotics, or surveying drones. Moreover, this creates an uneven level of evaluating productivity across construction organisations. The other limitation is that the study observed companies listed on the cidb ROC in South Africa across the categories 4-9. This excludes a large number of those firms in lower categories. This is mainly due to the assumption that companies in the higher-ranked categories have resources and manpower to digitalise, and the inquiry to observe their productivity output is imperative. Lastly, the study is limited to the information provided by the respondents (both through the interviews and self-reporting information through questionnaires). The views and collating of this information present the margin of the industry professionals' perceptions and level of exposure to digitalisation in South Africa.

1.12 Structure of dissertation

Chapter One: Introduction

Chapter one introduces and provides the core fundamentals of the research and elaborate introduction of the research topic. This chapter presents the background to the research study. Additionally, this chapter presents the problem statement, research aims and the research objectives of the study. Furthermore, the research questions and its subsets are presented with justification rooted in the literature. Moreover, this chapter provides an overview of the research methodology and data analysis methods used, as well as the scope and limitations of the study.

Chapter Two: Literature Review

This chapter provides an in-depth analysis of the literature relevant to the research study, examining its intrinsic and theoretical aspects. This culminates from the compilation and synthesis of literature underpinning digital technologies utilized in the construction industry (both soft and hard technologies). The extant review of literature additionally assesses the

impact of productivity on construction projects from the optic of cost minimization and time reduction on construction projects. Managerial, technical and organizational factors impacting the adoption of digital technologies are further analysed and linked to the South African built environment context. The chapter lastly addresses the methods and frequencies of training and ease of adoption of digital technologies in the modernization of the construction industry to fully digitalise.

Chapter Three: Theoretical and Conceptual Framework

A theoretical and conceptual framework are provided in this chapter. Theoretical framework is developed from a plethora of theories underpinning the shift to digital technologies, impacts of project productivity (cost and time optimisation) as well as the skills and training methodologies. This developed conceptual framework is pertinent for the establishment of the research hypotheses envisaged for this study.

Chapter Four: Research Methodology and Design

Chapter four outlines the research methodology used. This further included the method of data collection and the techniques of data analysis. A research philosophy is presented together with the research paradigm and research strategy adopted for the study. A population identification, sampling techniques, and selection of the sample are further explained in this chapter.

Chapter Five: Data Presentation

Chapter five presents the data obtained through the quantitative research approach. The obtained data is presented in a raw format, presenting the respondents' perception and input to the distributed questionnaire/data instrument.

Chapter Six: Data Analysis and Discussion of Findings

This chapter discusses the findings that were obtained from the quantitative research instrument distributed to the respondents in this study. These findings are analysed to either validate or refute the hypotheses stated in Chapter One with the research tools and techniques highlighted in Chapter Three. The nexus of the data analysis is achieved through the direct relation between existing literature relating to digitalisation, project productivity, enablers, and barriers of digital technologies. Additionally, the training and exposure of digital technologies, when compared to the already existing literature.

Chapter Seven: Discussion of Findings

Chapter seven presents the findings of the study. This chapter interrogates the findings through the data analysis techniques discussed. These findings are presented in accordance with the research objectives and the research hypotheses.

Chapter Eight: Conclusion and Recommendation

Chapter eight presents the summary of the findings from this research study. This chapter additionally echoes the research objectives, and a detailed discussion of how each objective has been justifiably answered with the analysis of the data and testing of the hypothesis. Additionally, recommendations are made for this study and its potential areas of improvement should the study be undertaken in another context or with a larger population of participants.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter explores the fundamentals of digitalisation in the construction industry. Furthermore, the chapter does an extensive interrogation of literature assessing relevant factors and themes that necessitate the adoption of digital technologies in the construction industry, particularly in the advent of many industries at the precipice of migrating all their operations to a digitalized environment. Additionally, this chapter explores all the variables that either impede or enable adoption of such technologies on the construction projects in South Africa. Notwithstanding that, this chapter also provides an overview of the elements or dynamics that intrinsically affect a development or construction phase when utilising digital tools and techniques. This chapter firstly traverse the evolution of digitalisation across centuries in order to understand what pillars of the economy are impacted by this phenomenon to ultimately see a myriad of industries exploring the digital pathway in their operations, the construction industry not being an exception.

2.2 Evolution of technological innovation

A significant shift in the production and manufacturing industry took place in England during the period 1750 – 1840, which to date has changed the trajectory of how manufacturing and industrialisation conduct their operations. This was the mark of the first *industrial revolution*, which scholars and historians define as a period under which a rapid shift that disrupted the economy occurred and was followed by a rapid growth in the migration of the workforce from agriculture into the manufacturing and mining sector, and subsequently, increasing the national household income (Ashton, 1997; Agarwal and Agarwal, 2017). This disruption in the economic and labour facet of the economy was largely evidenced through the railway industry of the time (Ashton, 1997). This industrial revolution was dubbed the greatest catastrophe that befell England (Ashton, 1997). This was primarily due to unfavourable social consequences of rapid migration to big cities, increased pollution to the environment, and physical exertion to labourers' wellbeing being observed at the time. This revolution is however, considered a hallmark of progress in the modern-day disruptors of economic, social and intellectual innovation (Chandler Jr, 1993; Ashton, 1997; Landes, 2003; Kavuri *et al.*, 2020). In the early nineteenth century, the momentum and rapid growth in the manufacturing and mining sectors

reached a plateau. It was during this period that the advent of the second industrial revolution emerged, which was between the years 1870 - 1914 (Mokyr and Strotz, 1998; Agarwal and Agarwal, 2017; Kavuri *et al.*, 2020; Stearns, 2020).

Throughout the Second Industrial Revolution, significant technological advancements and innovative tools were developed. Agarwal and Agarwal (2017) posits that it was during this industrial revolution that an unorthodox amalgamation of technological systems (tools), financial advancements, and social cohesion developed. These included systems such as banking, manufacturing, internal combustion engines, and electric motors (Taalbi, 2019). The merger across all these systems evidenced an enhancement in economic growth and, conversely, gave rise to sustainable income-generating techniques (Ashton, 1997; Mokyr and Strotz, 1998). Mohajan (2021) reports that it was during this industrial revolution that Henry Ford focused on the assembly line during the production of automobiles as a way to expand profit margins and increase output. Furthermore, the traditional construction methods (brick-and-mortar) experienced a shift in the pace at which adaptability had to mirror changes of the time. It was during this revolution that an increase in the production of electricity, steel, and reinforced concrete gave rise to the construction industry's ability to develop robust structures that can withstand external factors and still maintain a long-lasting aesthetic and cultural significance (Landes, 2003). Notwithstanding that, it is further asserted that the underlying factor enhancing the construction industry at the time was advances in accessibility and availability of energy, streamlined production of steel, and equipment used to build (Agarwal and Agarwal, 2017; Barbosa, Woetzel and Mischke, 2017). It was during this period that mass production was achieved across the West, and as a result, the construction industry was well positioned as one of the industries with a significant contribution to the GDP (Landes, 2003; Mohajan, 2021).

The third industrial revolution, which is referred to as “*digital revolution*” emerged in the late 1950s which is characterised by an exponential rise in mechanical and digital electronics (Gray and Rumpe, 2015; Taalbi, 2019; Mohajan, 2021). The third industrial revolution can be well explained by innovative technologies such as nanotechnology, biological (biomedical) technologies, information systems, 3D printing machines, artificial intelligence (AI), robotics, and a plethora of other innovative technologies (Gray and Rumpe, 2015; Mohajan, 2021). Mohajan (2021) draws comparison across the industrial revolutions in postulating that

economies which benefited from the first and the second revolutions, were primarily Western Europe, China and The United States of America (USA). This incites the dominance of global resources and an upper hand in refining potential defects in current technologies in order to create more advanced iterations of innovative tools (Agarwal and Agarwal, 2017; Taalbi, 2019; IDC, 2020; Mohajan, 2021). Notwithstanding that, this denotes a form of polarisation of digital resources and positions developing countries at a disadvantage in comparison to western countries (Mohajan, 2021). An emergence of wealth across economic sectors became prevalent across the world. This necessitated the development of innovative and digital technologies that adapts with the contingent needs of varying countries globally (Mohajan, 2021; Ebekoziem and Samsurijan, 2024). This is further purported by IDC (2020) and De Groen *et al.* (2017) in a study across European Union (EU) where countries such as Finland, Estonia and the Netherlands were recognised for their rapid ability to adopt digital technologies. Thus making them some of the countries at the forefront of innovation (De Groen *et al.*, 2017). The interrogation and layering of these three industrial revolutions and the emergence of the main innovations in their respective time frames, begs a poignant question that “*how is Industry 4.0 different?*”. In the same chronological unpacking, an observation of this revolution is made.

Industry 4.0 is a term that is globally used, the origins of which emanate from the German government’s reference to a high technology strategy (Strange and Zucchella, 2017). Philbeck and Davis (2018) corroborate this by positing that the emergence of the concept and idea of Industry 4.0 occurred in Germany between 2011 and 2015, with the substrate of the concept focusing on how digital technologies can be applied to manufacturing. However, interest in this concept has grown rapidly due to the rise of new and innovative technologies. Since the emergence of Industry 4.0, the uptake of its use across manufacturing, healthcare and software use; has evidenced a reported and improved productivity and use (Demirkesen and Tezel, 2022). Technological change and innovation are at the centre of any revolution across industries and faculties of society. This is supported by observations across several professional fields. In medicine, the use of advanced diagnostic imaging technologies enables more accurate diagnosis and improved treatment outcomes. In banking, multi-factor authentication systems enhance cybersecurity by strengthening access control. In the software and computing sector, modern applications are capable of performing complex calculations and generating precise results efficiently. Similarly, in engineering and manufacturing, robotics are increasingly employed in the production of components and goods to improve precision, efficiency, and

consistency. These advancements in technologies possess the capacity to advance economic growth and development of new skills across industries (Strange and Zucchella, 2017; Philbeck and Davis, 2018; Demirkesen and Tezel, 2022; Maqbool *et al.*, 2023; Adebowale and Agumba, 2024). Internet of Things (IoT), quantum computing, Artificial Intelligence (AI), smart materials and sensor systems are some of the modern system products of Industry 4.0. Notwithstanding that, across all its facets of their utilisation, productivity and efficiency are their key output (Demirkesen and Tezel, 2022; Tjebane *et al.*, 2022; Maqbool *et al.*, 2023; Adebowale and Agumba, 2024). A further understanding of the relationship between the use of these tools and the level of knowledge and skill becomes pivotal.

The critique and synthesis of the second industrial revolution (Mokyr and Strotz, 1998) poses a poignant caution in that without knowledge, there will not be technology. Conversely, the lack of what technological tools to adopt and use at a given instance minimises or eliminates the conception of such a technology. This postulation is prevalent across the South African construction industry, particularly in the utilisation of digital tools not familiar to the stakeholders, especially in understanding the possibilities of how they advance productivity (Awodele *et al.*, 2023). This analysis is devoid of placing and understanding the intricate factors which impedes and delays the adoption of digitalisation in a contextual setting. However, there is marginal knowledge relating to digital tools, especially in choosing, using, and optimising the digital tools for the advancement of project productivity (Osunsanmi *et al.*, 2018; Tjebane *et al.*, 2022). This is further elucidated by the industry's long-standing reputation of lower levels of reported productivity (Barbosa, Woetzel and Mischke, 2017). However, it is imperative to start from this juncture in exploring the core of how construction productivity is perceived. Moreover, when interrogated from the viewpoint of technological integration.

It is from this point of departure that this study establishes its position within the sustainability framework. Furthermore, evaluating inhibitors to the implementation of digital tools is observed. It stands to be noted that the sustainability strand underpinned by the Sustainable Development Goals (SDGs) is interrogated in positioning this study (Regona *et al.*, 2024). In doing so, the study further expands the scope of focus to measure the role the government has had in the advancement of digital adoption within the construction industry. This is fundamental for the study, as other countries around the world have formalised methods to govern and expedite the implementation of digital tools. This is additionally extended to

construction industry boards. Several digital technologies, software and robotic components exist, and some have been legislated into the operations and tendering processes in other countries. This is done as an effort to minimise cost and time overruns on construction projects with minimal wastage across material, workers and turnaround time from procurement departments (Barbosa, Woetzel and Mischke, 2017; Emmanuel *et al.*, 2018; Lefoka, 2019; Ikuabe *et al.*, 2020; Aghimien *et al.*, 2021). As a result, understanding how digitalisation forms part of the SDG goals in addressing the objective of minimal impact to the environment and the advancement of industrialisation, a further interrogation of the SDGs is detailed.

2.3 Nexus between sustainable development goals (SDG) 9 and digitising the construction industry

Regona *et al.* (2024) postulates that in so much as the integration of digitalisation in the construction industry has been advocated for, there remains an integral investigation of the correlation between its efficacy and Sustainable Development Goals (SDGs) objectives. Furthermore, a multifaceted dissection of how digitalisation impacts the construction industry remains a point of departure before full adoption across the industry is achieved (Regona *et al.*, 2024). In 2015, the global world leaders of both developing and developed countries convened at the United Nations (UN) conference. At this conference, a 2030 agenda which advocates for various initiatives across the socioeconomic, social and political landscape, was proposed. The main objective of this agenda was referred to as the Sustainable Development Goals (SDGs) (UN, 2015). As can be seen in Figure 2.1, the amalgamation of these global leaders synthesised the SDG objectives into 17 Goals and Goal 9 “*Industry, Innovation and Infrastructure*” is acutely a substrate of this research. However, the study only assesses the integration of innovative tools about their adeptness in forging the philosophy of SDG Goal 9 within the construction industry (Lu *et al.*, 2024). The pretext behind focusing on the SDG Goal 9 is reinforced by the use of innovation (Industry 4.0), perceived to improve productivity in the construction industry. However, this remains to be explored as the construction industry expresses a reluctance and in certain instances, experiences barriers in fully exploiting the benefits of digitalisation. Moreover, the SDG Goal 9 explicitly sets out the targets and maps those targets against the ability and proficiency of the construction industry, and whether these can be achieved or not. Additionally, these targets are primarily dissected through the benefits (advantages) of the various digital technologies available for use in the construction industry, whereas disadvantages are also evident.

One of the targets of Goal 9 is to foster resilience in growth across the various forms of infrastructure development. These infrastructure projects comprise a complex system of management, monitoring and reporting of the work progress. However, Goal 9 can achieve this through the utilisation of drones or unmanned aerial vehicles (UAVs), employing the duality of IoT in promoting expedited processing and analysis of data. Additionally, the use of VR aids in identifying errors and marking areas of improvement across a project. As a result, the utilisation of such technological tools allows for ease of monitoring and overseeing the construction project (Adebowale and Agumba, 2024).

Literature posits that the construction industry is fragmented and this hinders a collaborative engagement of all stakeholders in bringing a project to completion on time and within cost (Mohd Nawi *et al.*, 2014; Boadu *et al.*, 2020; Lu *et al.*, 2024). One of the targets of Goal 9 is to promote sustainable industrialisation (collaboration of stakeholders on a project from design through to completion) (Maskuriy *et al.*, 2019). Depending on the type, size and nature of the project, various innovative technologies can be employed to advance this collaboration in an organised order. Systems such as BIM enable the professional team to edit drawings, rectify omissions, and finalise their designs in real-time. Especially when requests for information (RFIs) are conducted in a traditional way of going through a document control portal. Furthermore, VR and AR simulations have been shown to have the capacity to recreate a project and, as a result, allow early detection of errors, overlay of services (water and electricity), as well as to ensure transparency from a cost perspective (Adebowale and Agumba, 2024).

The argument situated within the Sustainable Development Goals (SDG) mandate is central to the core research problem of this study, particularly in its examination of the relationship between digital technologies and productivity within the South African construction industry. The SDG framework provides a normative and structural lens through which issues of development, capability enhancement, and industrial transformation can be critically assessed. In this context, it becomes especially relevant in addressing persistent systemic challenges that hinder productivity improvement. A key gap identified in the study is the limited capability and inadequate skill base within the South African construction sector, which directly contributes to declining productivity levels. This challenge is further compounded by insufficient investment in digital transformation initiatives, as well as a perceived lack of proactive engagement from government stakeholders in facilitating technological adoption and

innovation within the industry. These factors collectively create an environment in which productivity enhancement remains constrained, despite the availability of emerging digital tools and methodologies. The SDG mandate offers a comprehensive and actionable framework for addressing these challenges by promoting inclusive, sustainable, and innovation-driven industrial development. It encourages stakeholder alignment around shared developmental objectives, thereby fostering an environment conducive to capacity building, technological diffusion, and institutional reform. Importantly, it also provides a globally recognised benchmark against which national development efforts can be evaluated, ensuring that countries adopting the framework remain aligned with its foundational principles of sustainability and equitable growth. Furthermore, this research is underpinned by a conceptual framework that systematically analyses the barriers and enablers influencing productivity, alongside the role of digital technologies in optimising construction processes. By positioning the SDG framework at the centre of this analytical inquiry, the study gains a multidimensional perspective that strengthens both its interpretive depth and analytical rigour. Consequently, the integration of the SDG lens not only enriches the interpretation of findings but also enhances the practical relevance and policy implications of the research outputs.



Figure 2. 1: Sustainable Development Goals (SDGs) according to the United Nations (UN)

2.4 Key gaps in digital adoption in South African construction industry

It is noted that endemic to the construction industry, is the slow pace of adoption of digital technologies (Osunsanmi *et al.*, 2018; Maqbool *et al.*, 2023). Notwithstanding that, the South African construction industry is no exception. Literature purports that the South African construction industry lags significantly behind its global counterparts in the pace of adoption, implementation and appreciation of digital technologies (Tjebane *et al.*, 2022). This slow rate of adoption is a notable factor that emanates from a plethora of reasons that environmentally affect the South African dynamic of the construction industry (Smidt and Jokonya, 2022). Aghimien *et al.* (2021) posits that the South African construction industry has experienced a surge in the introduction of new digital tools and software such as Building Information Modelling (BIM), drones, IoT sensors, and cloud-based project management tools, and widespread integration. However, the degree of implementation, particularly an accelerated means, still seems to be a complex hindrance (Awodele *et al.*, 2023). The economic, socio-economic, and lack of digital skill, are three focal factors that impede the adoption of innovative technologies. Moreover, some of the factors associated with these marginal levels of adoption lie outside the jurisdiction of the parties involved in the construction endeavour (Aruleba and Jere, 2022). Some of the factors giving rise to this glacial pace of adoption in the South African construction industry are discussed.

Similar to the global landscape across various sectors of the economy, economic volatility (uncertain global economic disruptions) and economic constraints (the currency's low buying power) are some of the variables that impede the accelerated adoption of digital technologies in South Africa (Demirkesen and Tezel, 2022). From an economic perspective, the cidb aggregates contractors across Grades one (1) through to nine (9). Financial capability and cashflow are the core determinants of a company's or contractor's ability to procure digital tools needed for the construction endeavour. This further forces contractors without the economic leverage to see no viable motive to expend their marginal profits on expensive digital technologies. As a result, the aversion to adopt prevails and stagnates a contractor within a particular cidb Grade. As a result, the vast majority of construction companies or contractors prioritise a company's survival over the uncertainty of implementation of new digital technologies.

A large proportion of construction companies registered on the cidb ROC are small and medium-sized enterprises (SMEs) (cidb, 2022). These companies make up a large portion of the South African construction sector. However, (Kongolo, 2024) purports that these companies operate on narrow profit margins and perceive the investment in digital technologies such as BIM software and drones (UAVs) to be exceedingly expensive for their company size as well as the project types they undertake. Since these companies do not have a consistent and strong financial reserve, they exhibit a reluctance towards the appraisal of digital innovation.

South Africa has one of the highest levels of inconsistent output of Science, Technology, Engineering and Mathematics (STEM) qualifiers (Franklin, 2024). The redress of this inconsistency is also met with inactive efforts from the government. The underinvestment in training and enhancing the skillset of South Africans in STEM is one of the notable factors that slows the capacity to digitalise construction activities. Attempts from the gazetted 2020 National Digital and Future Skills Strategy of South Africa have not evidenced any feedback on how the training, exposure and reinforcement of STEM in the digital age compares against the fast pace of digitalisation in other industries and sectors around the world (Franklin, 2024). According to Centre for Security and Emerging Technology, China leads with over 40% STEM. Graduates (Oliss *et al.*, 2023).

Digitalisation requires a strong workforce that is both proficient in construction techniques and in information technology, data management, and software skills (Lu *et al.*, 2024). A notable observation among construction managers, architects, engineers, and cost estimators is their unfamiliarity with new digital tools, systems, and software already in circulation in other parts of the world, which reports optimal productivity in the construction industry (Maskuriy *et al.*, 2019). Moreover, these systems require personnel with highly specialised technical skills to oversee their procurement, use, and maintenance, which is also a difficult pursuit in South Africa due to a lack of technical infrastructure. Institutions of higher learning and training are not exempt from criticism in light of the curricula which inform teaching budding professionals about digital tools and their use (Shojaei and Burgess, 2022). Nazarov *et al.* (2021) posits that the curriculum being used is outdated and largely lacks focus on the digitisation and innovative technologies. This further creates a regression in the attempt to produce graduates and professionals with a duality of skills (technical and digital) pertinent to the industry. As a result, this is one of the core pretexts behind the slow adoption of digital technologies.

The construction industry in South Africa is considered to be one of the industries with a strong aversion to change (Tjebane *et al.*, 2022). This is attributed to industry's reliance on manual labour and to the marginalisation of investment in training and upskilling labourers for critical operational skills. Moreover, scholars posit that a conservative attitude and scepticism are barriers prominently observed across construction companies and stakeholders (Berlak *et al.*, 2021; Siddiqui, 2022). This is further perpetuated by the contractor's inability to measure the benefits of digitalisation within a short period. Additionally, the complexity and skill required to operate some of the digital tools in the construction industry are considered complicated and time-consuming (Ikuabe *et al.*, 2020; Al Omari *et al.*, 2023). Furthermore, it can be inferred that uncertainty surrounding digitisation represents a significant concern within the South African construction industry. In addition, insufficient skills and limited exposure to digital technologies through STEM programmes reflect a related challenge regarding the slow pace of digital adoption. To understand the strategic approaches required for industry-wide digitisation, it is necessary to examine the frameworks that underpin the digitisation process.

In the analysis of the research gaps pertinent to South Africa, not adequate empirical data is presented and found across the impact and effect of the efficacy and the benefits of digital technologies across construction projects. This creates a vortex of indescribable phenomena through which a mode of uniformity in understanding the degree of impact can be objectively deduced. Moreover, the suggestion and critique prevalent to STEM curricula being a component of the root cause, is unsubstantiated and linked to the required skills to select, operate and maintain the use of digital technologies. Furthermore, skills and a set of barriers are not linked to empirical evidence or rigorous inquiry set in theory and practice. As a result, the research framework developed through theory for this study, undertakes to fully explore and understand the impacts of skills, barriers and digital technologies to expended productivity.

2.5 Framework for digitalisation

Although digitalisation is the new *modus operandi* for many sectors of the economy, its implementation relies on a multitude of factors. Berger (2016) incites that, for the construction industry to fully experience the benefits of digitalisation, a substrate must be established through which the potential of these new innovative methods of construction, can be assessed and evaluated. Additionally, they further expand this assertion at the back of a study conducted across Germany, Austria and Switzerland through which they established a model that denotes

their findings. The framework established is split into four quadrants (Figure 2.2). This figure establishes that coordinated synchronization of digital data, access, automation and connectivity yields desired levels of productivity output for a project. In addition to that, this can establish a basis for duplicating this framework for any organisation, regardless of size, location or system type. In the assessment of the implications of this framework, it is important to understand what these four quadrants mean in relation to the development of a construction project framework for use on projects.

Berger (2016) asserts that digital data primarily focuses on a central part of the organisation: the collection and analysis of data through digital platforms. This is deemed crucial in that much of the construction project's success relies on the quality of information and clear models for disseminating data across all the stakeholders involved in the project. This is further expanded by the insight that the value chain is the arch under which a series of activities occur; as a result, the linkages and transfer of information across these interactions are understood. Furthermore, the assessment of these linkages can enhance the value chain in optimisation of resources, labour and time (Lu *et al.*, 2024).

The automotive industry depicts the application of this quadrant (digital data) very well. In their synthesis of automation, Berger (2016) they argue that automation is a direct result of amalgamating large amounts of data to create autonomous systems that operate independently across multiple interfaces, thereby enhancing project productivity. Furthermore, automation can also be considered to have self-organising capabilities which are useful during the error identification process, troubleshooting and reverting to ascribed data for regeneration to operate as specified. However, literature commonly perceives digital access as having physical access to mobile devices across the construction project (Maskuriy *et al.*, 2019; Ikuabe *et al.*, 2020; Mahajan, 2021). Notwithstanding that, Berger (2016) asserts that digital access is the opportunity and ability provided by physical mobile devices to access both the internet and the intranet. This sentiment is further elaborated by Agarwal *et al.* (2016) establishing the benefits of having an internet connection and access through all the handheld platforms on-site. This significantly has the propensity to improve both efficiency and collaborative endeavours. An argument that digital access can sometimes pivot the trajectory of the project based on limited access and inability to use the said tools, is one to be noted as this can impede project productivity (Sutherland, 2020). However, a set of preventative measures to acquaint all the

personnel on site is an essential part of this integration for a profitable project.

The final quadrant is that which underpins connectivity (Berger, 2016). This is described as the ability of a digital tool adopted on a construction project to have full synchrony of data, systems and functionality of the various activities on site. Connectivity is perceived to be a cornerstone function for digitalisation on construction projects and benefits the project in productivity optimisation (Barbosa, Woetzel and Mischke, 2017; Barbosa, Woetzel, Mischke, *et al.*, 2017; De Groen *et al.*, 2017; IDC, 2020; Mahajan, 2021). However, it is argued that this sentiment holds true in the event of *ceteris paribus* (all else being equal). This means that in other parts of the world, this is not the case across the construction industry. This can further be evidenced by the consistent planned power reduction across the grid in South Africa. This significantly impedes the pace with which digitalisation is adopted in the industry (Sutherland, 2020), along with many other factors such as location, type of service provider and proficiency in the use of digital tools. As a result, this benefit has an impact on project productivity.

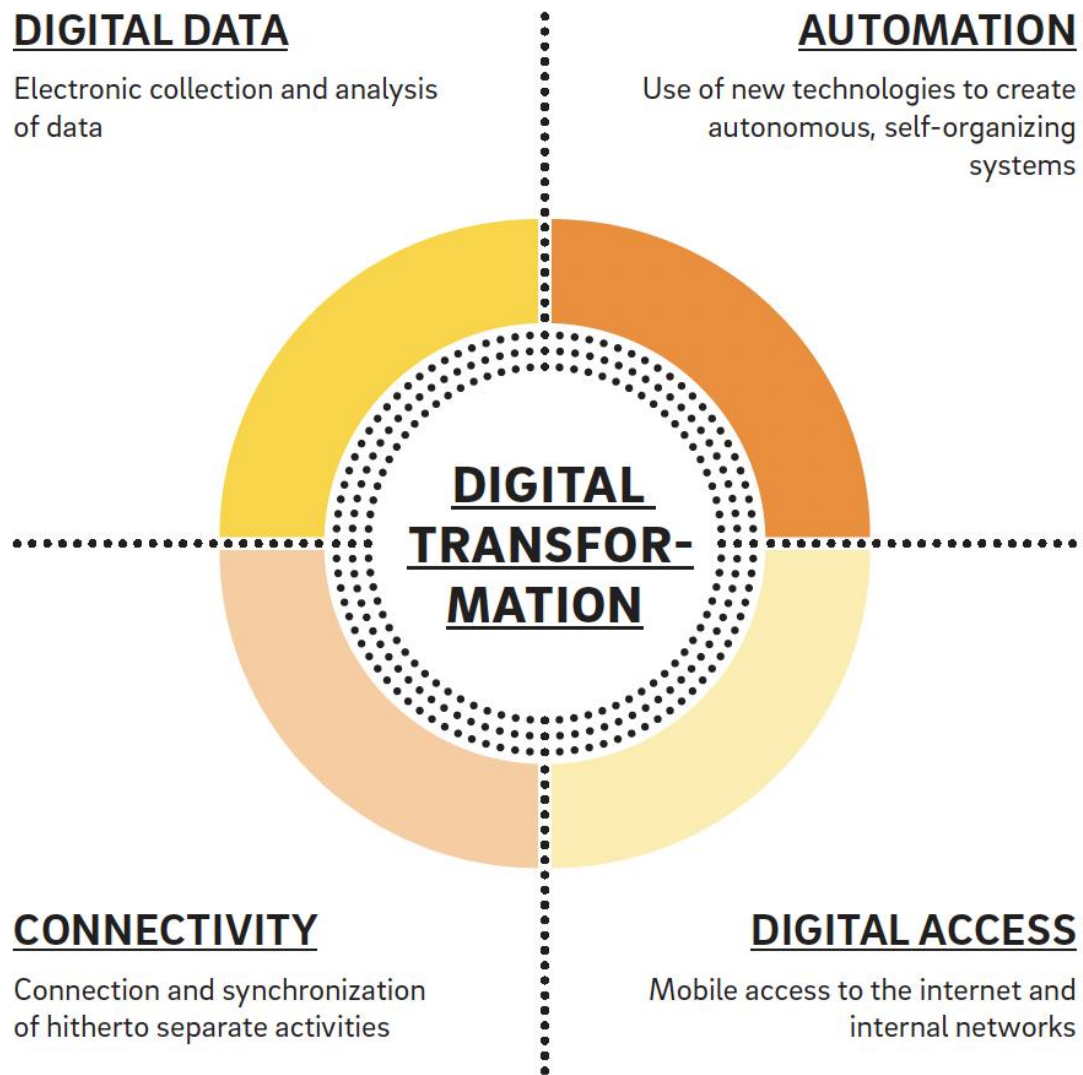


Figure 2. 2: Digitalisation Framework (Berger (2016))

Figure 2.2 serves as a foundational element of the study's conceptual framework by identifying key dimensions of digitalisation that remain insufficiently integrated within the South African construction industry. This limited integration is considered a significant constraint to the generalisability of findings concerning the relationship between digitalisation and productivity. The conceptual framework is therefore structured around the principal constructs identified in Figure 2.2, namely digitalisation types, skills, and barriers. These constructs are synthesised to develop an analytical model suitable for investigating the influence of digitalisation on productivity. Furthermore, the framework facilitates the formulation of hypotheses aimed at examining the nature and extent of this relationship.

2.6 Benefits of the adoption and implementation of digitalisation in the construction industry

Digitalisation in the banking, automation and construction industry has been perceived as a significant contributor to productivity globally (Ojala *et al.*, 2022; Bargoni *et al.*, 2024). Sectors such as manufacturing in Germany reported an improvement in productivity of 34.1% which is still growing (Berger, 2016). An endemic concern in the construction industry globally is the decline in the levels of productivity (Barbosa, Woetzel, Mischke, *et al.*, 2017; IDC, 2020; El Asmar *et al.*, 2021). Intrinsic to some of the core factors attributed to this are delays (material, plant and labour), rework and overruns, and poor levels of management strategies (Alinaitwe *et al.*, 2005; Baloyi and Bekker, 2011). Notwithstanding that, the aversion to digitalising is considered a contributing factor to the consistently poor levels of construction productivity across projects. This aversion can be correlated to certain factors.



Figure 2. 3: Integrated and core benefits of digitalisation in the construction industry (Agarwal *et al.* (2016)

The resources available for innovation in the construction industry are categorised into three levels of project development (design phase, development/construction phase and lifecycle phase). The advent of digital technology, particularly when integrated into the construction industry, has had a notable transformative impact on the operation and running of construction projects. This has also been observed across other industries, both locally and globally (Ibem and Laryea, 2014). Without exception, the South African construction industry has reported a myriad of benefits enhancing project productivity from inception, across development and spanning through the life-cycle phase of a development/project. Agarwal *et al.* (2016) provides a synthesised split of the uses, benefits and the types of technologies considered across these three levels. Maskuriy *et al.* (2019) corroborates this in positing that when digitising, a strategic framework is necessary. Figure 2.3 provides a synthesis and split of the strategic framework and signifiers (Agarwal *et al.*, 2016). These are higher-definition surveying and geolocation, next-generation 5-D building information modelling, digital collaboration and mobility, the internet of things and advanced analytics, as well as future-proof design and construction. These five signifiers emphasise that collaborative efforts reinforce versatility of technology used, allow autonomous operation of different technological tools and additionally allow the systems incorporated in the construction industry to manage large amounts of data generated at each level of the development. It is thus imperative for this study to explain the fundamental benefits of digital technologies in the construction industry at each phase of the development.

The construction industry is characterised by the traditional methods of construction, brick-and-mortar. A consensus observed across scholars in this field, is that which advocates the migration of these methods to digital mode (Berger, 2016; Barbosa, Woetzel, Mischke, *et al.*, 2017; Maskuriy *et al.*, 2019; IDC, 2020; Aghimien *et al.*, 2021; Chen *et al.*, 2022; García de Soto *et al.*, 2022). However, measurable benefits of this endeavour, are not known. Moreover, the metric used to measure these benefits, are not consistent from project to project as well as from country to country (Omari *et al.*, 2023). In lieu of the assertion that digitising improves productivity, an evaluation of these benefits is conducted and reported.

2.6.1. Improved Communication Across Professional Team

Improved and expedited communication across the professional team (engineers, cost engineers, client and stakeholders) is considered one of the benefits of digitising the construction sector (Berlak *et al.*, 2021). This attribute ensures that all the professional team members can distribute and receive communication regarding the design of a structure and the

progress of the project in real time (Barlish and Sullivan, 2012; Berger, 2016). This reliance is considered significant in that it guarantees a reduction in time wastage and idle time pertinent to the project (Ibem and Laryea, 2014; IDC, 2020). Furthermore, the introduction of a 4D-BIM object-oriented building model, currently introduced in the construction industry, has an integrated time dimension, which makes the model achieve this objective (Berger, 2016). Time is a significant component of the planning and development stage of a project (Alinaitwe *et al.*, 2007). Through the sequential planning of a construction project, time as a resource can either delay the project or affect the cost. Berger (2016) posits that across the construction industry, only 6% of the 4D-BIM model is used globally. The interrogation of this marginal uptake is a key point that this study also aims to explore. Miscommunication among construction professionals is considered another deterrent to productivity. This has a consequential effect of giving rise to rework, which results in an inflated cost of the works (Makulsawatudom *et al.*, 2004). This collaborative feature in the adoption of digital technologies both benefits and encourages accelerated uptake in the adoption of digital technologies.

As communication occurs at each stage of development, it is imperative that digital tools used during project development are stated. During the development phase, drones, robotics, 3D printing facilities and mobile devices are used for communication purposes. These communicate the progress of the project, quantity and scope of an activity to be conducted, as well as expected quality (Makulsawatudom *et al.*, 2004; Barlish and Sullivan, 2012; Shojaei and Burgess, 2022). It can therefore be inferred that digitisation facilitates and improves communication across the various stages of a project lifecycle.

2.6.2. Enhanced procurement and supply chain management

One of the fundamental activities in the construction industry is the procurement of materials, labour and skilled/specialised plant to execute the project as per the specification. This endeavour can prove to be tedious, particularly if it is conducted in the old adage pen-and-paper method, which, as reliable as it is, can sometimes put the project at risk if the documents are not stored properly or backed up by some form of digital repository. Notwithstanding that, the introduction and implementation of digital technology to oversee this process of procuring plant, equipment and labour can be done seamlessly across any level of the construction project. Berger (2016) postulates that, much as procurement significantly contributes a large portion of the project cost, these costs can be drastically reduced and minimised by the

utilisation of digital technologies. This assertion is further expanded by Bienhaus and Haddud (2018) postulating that digitalising the procurement process significantly contributes to supporting and encouraging complex decision-making processes. Furthermore, this ensures that an organisation or a project can centralise their focus to a more strategic procurement model, which factors a multitude of variables which could otherwise not have been considered. Additionally, the digitalisation of the procurement process, if done according to the rudiments of the organisational strategy with the objective of reducing costs, can yield a positive productivity output (Bienhaus and Haddud, 2018).

A point raised by Berger (2016) is that the migration of procurement division of an organisation to a digital platform has reported a cost saving of around 5% of the overall procurement costs. This thus purports and encourages digital procurement systems as alternative avenues, particularly in the current uptake of technological systems across various economies (Berger, 2016; Bienhaus and Haddud, 2018; Maskuriy *et al.*, 2019; Tjebane *et al.*, 2022).

2.6.3. Integration of robotics and human labour for improved project performance

An endemic problem in the construction industry, dating back to the inception of the industry, is the concern with time overruns, cost overruns and compromised quality of the project (Olomolaiye *et al.*, 1987; Kaming *et al.*, 1998; Sweis, 2000; Love, 2002; Makulsawatudom *et al.*, 2004; Baloyi and Bekker, 2011; Durdyev and Mbachu, 2011; Hughes and Thorpe, 2014; Neve *et al.*, 2020). The construction projects vary in complexity and the degree of interconnection among the various trades. This complexity is evidenced and observed across different types of construction projects, thus making the complexity of a project a variable of concern against the project's success (Love *et al.*, 2002; Berger, 2016; Nikmehr *et al.*, 2021). It is thus reasonable to deduce that with the increased complexity in the project delivery, cost and time can be significantly impacted. However Berger (2016), purports that the digitalisation of construction activities, amidst the complicated processes and their interconnectedness, can be the one singular resolve to the endemic crisis of cost and time overruns.

Nikmehr *et al.* (2021) explicate that the construction industry has a human capital component that is skilled and knowledgeable, technological infrastructure that can supplement the needs of the ever-changing project environment, as well as the capacity to integrate skills across sectors for the advancement of the industry. This assertion is supported by (Berger, 2016) in

noting that project complexity is an insignificant hurdle to overcome. Furthermore, in doing so, a lot of changes such as improved productivity, reduction in cost and time overruns, and enhanced project quality can be ascertained. It is noted through literature that the use of drones, use of advanced mobile devices and the utilisation of 3D laser mapping technology have evidenced enhanced project quality and reduction in project cost and time (Barlish and Sullivan, 2012; Berger, 2016; Chowdhury *et al.*, 2019; Maskuriy *et al.*, 2019; van Wyk *et al.*, 2024b).

Over the past decade, the adoption and integration of drones within the construction industry have evolved as a significant extension of established site management practices. This is conducted as such to ensure that a full overview of the project is observed by both the project team and the client in real time as the construction workers are proceeding with the work (Mahajan, 2021). Furthermore, this is to ensure that any digression in the work breakdown structure (WBS) as discussed before the work commencement of any activity can be identified and remedied without causing a lag time to the project. A fundamental responsibility of a project manager, construction manager, or site supervisor within a construction project is to ensure effective communication among all parties involved, including project stakeholders. Barlish and Sullivan (2012) and Berger (2016) expands on this by positing that 90% of the CM's time is dedicated to communication. Notwithstanding this, it is evident that if there is a communication breakdown at any level of the project development, this can pose a serious threat to the performance and profitability of a project. As a result, advanced mobile devices ensures that if at any given point there is a change in the construction programme, the scheduled work to be done, a revision in the drawing from any of the professional team or an external occurrence that can halt the construction of a project; all the members involved in the project are alerted in real time (Ibem and Laryea, 2014; Berger, 2016; Leviäkangas *et al.*, 2017; Mahajan, 2021). The other important element is the waste reduction monitoring, which can be embedded in the integration of both robotics and human labour. This element identifies and alerts the material dispatch as well as the management component of a project in providing mitigative measures to the wastage of material. Moreover, this function leads to the prevention of overruns and the imminent compromising of project quality (Maskuriy *et al.*, 2019).

Project setting establishes the perimeter (boundary line) of a development. This is traditionally conducted with traditional surveying equipment. However, a 3D laser mapping technology can

be used to execute this function with less labour component and within a faster time frame (Berger, 2016; Kong and Lv, 2021). A characteristic of 3D laser mapping technology is the complex component detection feature (Kong and Lv, 2021). This characteristic is expanded further by both Berger (2016) and Nguyen *et al.* (2020) in positing that a significant amount of information regarding underground water, electrical cables and sewer connections underneath the ground, is detected and surveyed. Furthermore, this data is fed back to site management for better planning. As a result, it is evident that digital technologies can have a significant impact on setting out and establishing a site.

2.6.4. Health and Safety (H&S) co-ordination

A nexus exists between health and safety as a portfolio of a project as well as the various modes of digital tools used. Health and safety constitute a dynamic through which if not adequately implemented, could have the project come to a halt. This dynamic is evidenced when an accident occurs on site and the degree of effect brings a site to shut down. Furthermore, this also requires an investigation to the causation of the accident which can delay the project (Smallwood *et al.*, 2020). However, one ought not to be remiss to the reality that some accidents or incidents that happen on site, occurs out of the control of all parties, and as a result, no amount of planning can circumvent this occurrence.

There is a duality that exists when addressing H&S in lieu of the advent of digital technologies in the construction industry. The one polarity is advocating for digital tool utilisation for their ability to report incidents as they happen on projects. Not only that, report these incidents correctly and explicitly for the H&S officers to understand impacts on the projects. Additionally, gather and collect all the information regarding the activities which are to be performed on a project on the day and succinctly draw up a H&S plan which can be implemented. An equally important, though less frequently reported, dimension is the safe and responsible use of implemented digital tools, ensuring that neither workers nor users are exposed to harm or self-damaging outcomes. This is evidenced in the utilization of robotics and interference of external factors such as rain (moisture), power-cuts or improper assembly of such technologies which can give rise to such problems. However, Papulová *et al.* (2022) posits that due to the nature of how some of the devices used are easily programmable, the inciting of any change in disposition of operation, these devices can be re-programmed to better self-regulate and not pose a threat to the project. According to Trask and Linderoth (2023), the

application of digital tools to address H&S is not the trajectory that is supported. This opposing argument is based on the lack of maturity and understanding of the project scope, pathway conflicts across different activities and adequate evidence that has not been presented to advance the proportion of technology. This proposition contributes to the complexity that this study aims to explore, particularly when external factors are evaluated against the selected technologies, and exposure to use across the research participants.

2.6.5. Construction tendering amendment

The process of tendering for construction projects is a well-established practice within the construction industry. Over time, it has evolved and contributed to the development of iterative feedback mechanisms across the tendering functions of various organisations. Moreover, this process maintains a standard that doesn't deviate significantly from the economic changes such as inflation, exchange rates or implementation of a different procurement method (Bienhaus and Haddud, 2018). As much as various software and digital tools have been cited to be in use in the construction industry, BIM is the main globally used software. The software's ability to integrate multiple users at a time, through which input and rework of designs is achieved, is considered a new *status quo* for the future of project tendering (Berger, 2016). A mandatory stance established by the EU is that for the awarding of any government contract to any bidding contractor, the contractor must have a fraction of the tendered amount attributed to the use of BIM on the said project. This mandatory change or amendment to the tendering process can elicit a plethora of advantages for the construction industry, and the expedited uptake of digital technologies and the exploitation of their benefits for enhanced project productivity.

A benefit of this tendering data compilation incites the need for training in BIM (and other software). Additionally, transparency in the assembly of information necessary for the tendering process. Furthermore, Correa and Santos (2021) posits that document error reduction across various stakeholders can be achieved. A notable advantage that this can have on the tendering, project and quantifying the cost and time element, is that with BIM as a mandatory requirement, digital simulations of a project can easily be generated. These simulations can be carried out under different environmental conditions. Moreover, this could be an exercise that allows the stakeholders, contractor and the client to minimise errors when actual construction commences (Barlish and Sullivan, 2012; Berger, 2016; Correa and Santos, 2021). It should

further be noted that significant progress can be achieved through legislative and policy reforms aimed at streamlining and standardising Building Information Modelling (BIM) as a criterion in the awarding of construction contracts. Alternatively, consideration may be given to the adoption of other software platforms across construction projects that offer comparable functionalities and attributes.

2.6.6. Project visualisation

In the construction industry, completed drawings of a project are generally used as a means of visualising the product envisaged to be constructed. This comprises the various drawings from the architect, structural engineer, mechanical engineer and landscaping architect. However, with the advent of digitalisation, under which VR (Virtual Reality) and AR (Augmented Reality) are subsets, the visualisation of projects has transformed from the traditional 2D model to a 4D model. A significant benefit of VR is that this software has the capability to replicate the actual structure to be constructed so that stakeholders are able to see the project in all its intricacies (Schober *et al.*, 2016; Nassereddine *et al.*, 2022; Adebawale and Agumba, 2024). A widely recognised advantage of VR within the industry is its capacity to provide a comprehensive visualisation of a building's features prior to the commencement of construction. Additionally, VR allows for the entirety of the network of water, sewer and electrical pipes to be observed and assessed with regard to zoning lengths and installation to avoid incorrect pipes or having them unnecessarily cross one another. Moreover, if conflicting visual assessment is observed, VR ensure that adequate time is afforded to the alteration of drawings before construction commences (Nassereddine *et al.*, 2022). AR provides a comparable set of benefits when integrated into project development processes. Capabilities of AR are that the software allows for virtual site visits, increases the opportunities for collaborative work across both the design phase and project development, and provides methodical comparison between an as-built drawing and plan drawing (Nassereddine *et al.*, 2022). Furthermore, these capabilities combined with those provided by VR, it is evident that the exercise of visualisation enables the project to put in place preventative measures, which lead the project to cost and time overruns by identifying discrepancies in the designs from the onset (Berger, 2016; Nguyen *et al.*, 2020; Kong and Lv, 2021; Nassereddine *et al.*, 2022). This further promotes faster site establishment time and well-planned construction program of activities. Moreover, plant, equipment and labour component can be better managed (Aigbavboa and Kissi, 2025).

2.6.7. Faster project completion

A notable function, consistently emphasized in the literature, is the capacity of digitalisation and innovative technologies to reduce construction project durations. Berger (2016) asserts that there is a general consensus across 93% of construction industry professionals who agree that the implementation of digital tools in the construction industry can positively impact construction projects. This consensus is further reinforced by Arsić (2020) in stating that over the past 15 years, there has been a general decline in productivity across various sectors of the economy which the resolution of which has been the adoption and implementation of digital technologies. This further underscores the necessity for the strategic adoption of technological tools that can enhance productivity and thereby reduce the time required for project completion. Furthermore, Maskuriy *et al.* (2019) proposes a framework that assessed the efficacy of implementing digitalisation in the construction industry with the fundamental assessment being the observation of the time reduction of construction projects when assessed by offsite construction and lean construction. And digitalisation.

The framework evidenced that the reduction in time can be between 9,45% and 23,33% (Maskuriy *et al.*, 2019). This further supports the assertion that when implemented strategically, digitalisation can aid the profitability of construction organisations to achieve their objectives with a fraction of the overall project time. However, this cannot be assessed as a mutually exclusive component of the construction industry, given that the level of quality expected also needs to match the workmanship. The level of quality on construction projects is sometimes of concern, and this affects project productivity. This is largely evidenced by the rework and remediation of defective work. (Berlak *et al.*, 2021). Notwithstanding that, a resolution to this can be attributed to digital adoption tools, which mitigate this concern (Siddiqui, 2022). Furthermore, this can be attained through a project team composition comprising skilled, knowledgeable, and trained personnel in the utilisation of specified digital tools.

2.6.8. Financial (cost) management

A key factor in the development of any project is the financial management component of a project and a breakdown of both direct and indirect costs associated. In the past, the financial management of a project was not as intrinsic and complicated as seen in the modern-day construction practices (Aigbavboa and Kissi, 2025). Project complexity and the

interconnectedness of the various components exacerbate the probability of financial errors and accountability. These errors can halt the project or have the organisation responsible for the delivery of the project experience fines from Financial Governance Bodies such as the South African Revenue Services (SARS) in the case of South Africa. A synopsis of the different stages that need a thorough assessment and understanding during a project, is encapsulated in Figure 2.4, extrapolated from a book by Aigbavboa and Kissi (2025). The figure depicts the five fundamental steps that show the planning stage of the project resources. This stage is concerned with the fundamental need for proper planning of all the resources needed for the completion of the project. Cost estimation poignantly quantifies all the elements of a construction project and ensures that a definitive value is apportioned to the project across all the interconnectedness of the activities critical to the construction project. Cost budgeting allows the client, the professional team, as well as the contractor to understand the scope of limitation with regard to the financial and cost amount apportioned to them for their services. Furthermore, this allows the general management of the construction cost to be assessed and evaluated as the project progresses.

Cost control, on the other hand, refers to the systematic and rigorous management of expenditures associated with a project, ensuring precise accountabilities for all forms of costs incurred. Moreover, cost control can sometimes pose a serious concern if a project is subjected to abject incompetence within the contractor's role of executing the works. Furthermore, in the event that the incompetence is evidenced in the form of poor workmanship which requires rework of the project components, cost control can then be handled in a manner that can rigidly identify the error, apportion a cost to it and make good the work redone (Park, 2006; Wyman, 2018; Aigbavboa and Kissi, 2025). And lastly, cost reporting is the process through which a population of all intermittent project expenditures is compared to the initial budget of the project. Neumann *et al.* (2000) delineates this further in purporting that cost reporting is a presentation of how the budget is spent, what items related to the project were spent on, any variations in the budgeted amount compared to the final amount and the general performance of a project. Cost reporting is populated as a form of presentation of how the budget is spent to the stakeholders and all parties involved in the project (Neumann *et al.*, 2000; Berger, 2016; Wyman, 2018; Aigbavboa and Kissi, 2025). Although financial and cost management within projects is inherently complex, it remains essential to establish a clear connection between the benefits of digitalisation and the management of a project's financial portfolio.



Figure 2. 4: Financial Stages of a Construction project – inception to production (Aigbavboa and Kissi, 2025)

At the start of every construction project, a BOQ is compiled through a model preamble and standard system as a legislative governing document used in the construction industry. (Nadeem *et al.*, 2015) Nadeem et al. (2015) argues that this can be done through the utilisation of BIM software. However, there remains considerable debate regarding the effectiveness of this shift when compared to traditional costing methods. It can also be argued that the time reduction and error minimisation significantly improve the project time and cost. Furthermore, cost estimation and forecasting of a project can effortlessly be conducted through BIM. This software and its contemporaries aid in accurate cost estimation and forecasting by using historical data pertinent to the project or to a similar project in terms of scope. This is achieved by employing predictive analytics that gather data through IoT, Big Data, and algorithms embedded in the software's encryption. These techniques are considered efficient (Wyman, 2018) in their reliability in financial reporting.

The use of BIM, VR and ICT allows a tangible interface through which the budget spent is directly correlated to items it is spent on (Siddiqui, 2022). These digital tools enable real-time tracking of material expenses, subcontractor payments, acquisitions of plant and equipment, as well as the general project overheads. Software like construction project management platforms allows for instant updates through which the entire project team can gain access to

the portions of the work they are responsible for. This enables project managers to monitor budget spend and make provision for any adjustments. Another advantage of digitalisation of cost management is that automated invoicing through digital software, such as smart contracts, can be achieved. This allows for expedited payment of the work completed and subsequently permits the payment of service providers used on the project to be made without delay. This ensures that all the payments made are accurate, adhere to financial legislation such as SARS, and are processed in a timely manner. Furthermore, this substantially reduces administrative errors and the potential for disputes arising from delayed payments. In addition, it enables the construction organisation, as well as the project as a whole, to maintain a stable and consistent cash flow.

Wyman (2018) further highlight the significance of digitalisation in the elimination of an ingrained variable endemic to the construction industry which is resource wastage. Material management, labour management and plant management can easily be conducted with software such as BIM. This interface allows for the data reception, population according to groupings and analysis thereof. This software has the capability to track materials, labour and placement schedules, overhead resources used and ensure that a full account of the budget is adhered to and economically spent. This further allows collaboration and transparency across multiple stakeholders (client, professional team, contractors and service providers) in accessing necessary financial information pertinent to their job specifications (Berlak *et al.*, 2021; Chen *et al.*, 2022; Maqbool *et al.*, 2023).

2.7 Enablers of digital technologies used in the construction industry

Although the construction industry increasingly recognises and values the adoption of digital technologies, it is essential to critically evaluate the fundamental variables involved in the transition toward this phenomenon. It is argued that for an expedited and efficient way for digitalisation to be adopted in the construction industry, amendment of legislation is pivotal (Smidt and Jokonya, 2022). Legislative amendment is considered an arduous process, even though this has the inclination to aid expedited adoption within the construction industry (Awodele *et al.*, 2023). An enactment in policy that can both encourage collaborative engagement of stakeholders and enhance collegial utility of digital tools, is central to improvement in productivity and protection of systems, designs and project scope (Parusheva and Aleksandrova, 2022).

Construction industry professionals' acquaintance with digital tools is paramount to adoption (Hwang *et al.*, 2022; Adeniyi *et al.*, 2024). This interrogates the skill and aptitude that the professionals have in using digital tools in their professional practice. Papadonikolaki *et al.* (2020) argues that mandated to the professional councils, continuous learning and skills development is a crucial requirement. As a result, with the utility of digital technologies, especially at the development/construction phase of a project, there has to be evidence of familiarity, use and adoption in order to empirically assess the impact on construction productivity. While this is true, South African higher learning and skills development fraternity does not have an organised documentation used in upskilling the construction workers and as such, falls short of this premise. This further creates a challenge when one assesses the proficiency. As a result, an assessment and essential technical skills are precepts of adaptation to digital technologies. Table 2.1 highlights the findings from literature deemed to enable digitisation in the South African construction industry. According to Maskuriy *et al.* (2019), collaboration across professionals involved in the design and construction of the project can expedite the need for the government to enact and formalise the utilisation of technology. Table 2.1 provides a list of factors that enable digital technologies. These are clustered across four categorisations which are legislative and policy: training, skill and knowledge, risk association, and innovation. These are selected for this study given the structure of the research question and objectives stipulated.

The conceptual framework and development of the hypotheses for this study are grounded in the themes and constructs outlined in Table 2.1, which situate digitalisation within the context of the South African construction industry. Although existing literature identifies key enablers and barriers influencing digital transformation, there remains limited empirical evidence concerning the institutional structures necessary to effectively support and sustain these enablers. Furthermore, prior research has predominantly focused on barriers to digitalisation, with comparatively less attention given to the mechanisms through which enablers facilitate digital adoption and enhance productivity outcomes. This represents a significant research gap. Consequently, this study investigates how digitalisation enablers promote technology adoption and improve productivity within the South African construction sector.

Table 2. 1: Enablers of digital technologies used in the construction industry.

Field	Significant Findings	Extrapolated constructs	References
Legislative and policy	The legal and legislative component of the various contracts utilised in the construction industry, is one variable significant to change in adoption and application of digital tools. An operational framework guided by legal framework is pertinent to the industry. Multidisciplinary landscape of collaborative stakeholders can be appreciated through the legal and governance lens in the application of digitalisation. Amend the JBCC/FIDIC to enforce digitalisation to be an integral of public and private contracts tendering process. Construction professionals to work closely with institutional governing councils to amend standards.	Legislature, amendment of contracts, professional councils and adapting to change.	(Smidt and Jokonya, 2022);(Aghimien <i>et al.</i> , 2021); (Çıdık <i>et al.</i> , 2017)
Training, skill and Knowledge	Encouragement of the professional team is essential to adapting to the skills and knowledge required for digital use. Across the technical team on projects, a foundational understanding and use of digital technologies is essential. Depending on the levels of operation through the different organisation, a minimum requirement in education is essential.	Skill acquisition, education on digital tools and equipment, upskilling skills, training of construction personnel.	(Adeniyi <i>et al.</i> , 2024);(Omari <i>et al.</i> , 2023);(Demirkesen and Tezel, 2022)
Risk Association	Every technological tool (hardware or software) is enamoured with potential risks. These span the across the different stages and sections of work. An identification of risk factors such as human and financial, technological, legal, security operations and socioeconomic are delineated. Investment in the workers and training them to use technologies is central to project operations. The use of technology can prevent health, cost and waste risk of both material and plant on construction projects. Identification of misalignment in structural, architectural and mechanical drawings can be identified timeously. Human labour component is also cited to be under considerable risk with the utilisation of technology, and this is another area of concern that demands assessment and scrutiny across different sectors of the economy.	Legal, cybersecurity, economic feasibility, collaboration across stakeholders, investment, construction specialist innovators.	(Aghimien <i>et al.</i> , 2021); (Chen <i>et al.</i> , 2022); (Berger, 2016); (Barbosa, Woetzel and Mischke, 2017); (IDC, 2020).
Innovation	Through the use and application of digital tools across various stages of the project, significant benefits can be observed. These include cost minimisation as well as time	GIS, IoT, AI, 3D printing robotics, big data, VR, laser scanners, photogrammetry, BIM,	(Wang <i>et al.</i> , 2020);(Mahajan, 2021); (Maskuriy <i>et al.</i> , 2019); (Aghimien <i>et al.</i> ,

	reduction in some of the activities on site. Inventions such as GIS, IoT, AI, 3D printing robotics, big data, VR, laser scanners as well as photogrammetry have been assessed in relation to their utility and application. Ethical application is assessed in relation to off-site application as well as application across planning, designing and lifecycle component of the project. In the application of new technologies, capacity and knowledge across the organisational structure is critical for better use and yield of the desired output. In light of the migration to digital economy, the industry can increase the risk appetite in the appreciation of new technologies and software central to the profitability of the project. The project progress can easily be monitored, and quick identification of health hazards can be achieved.		2022); (Coates <i>et al.</i> , 2001); (Lang and Ramírez, 2017).
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2.8 Digital technologies and software utilised in the construction industry

There is a dearth of literature that specifically identifies digitalisation tools and techniques in South Africa (Brynjolfsson, 1993; Barbosa, Woetzel and Mischke, 2017). Ibem and Laryea (2014) conducted a systematic review of literature and identified thirty-six kinds of digital technologies and tools utilised in the construction industry. This review was conducted between the period 1993-2014 (Ibem and Laryea, 2014). These were categorised into specialised categories in the acquisition of data and programmable use on projects. These categories are data acquisition technologies (3D scanner or LADAR technologies), data processing and storage technologies (software application packages – predictive analytics and big data), communication technologies (Web 2 technology) and intelligent systems (Virtual Reality, Building Information Modelling, cloud computing technologies and robotics).

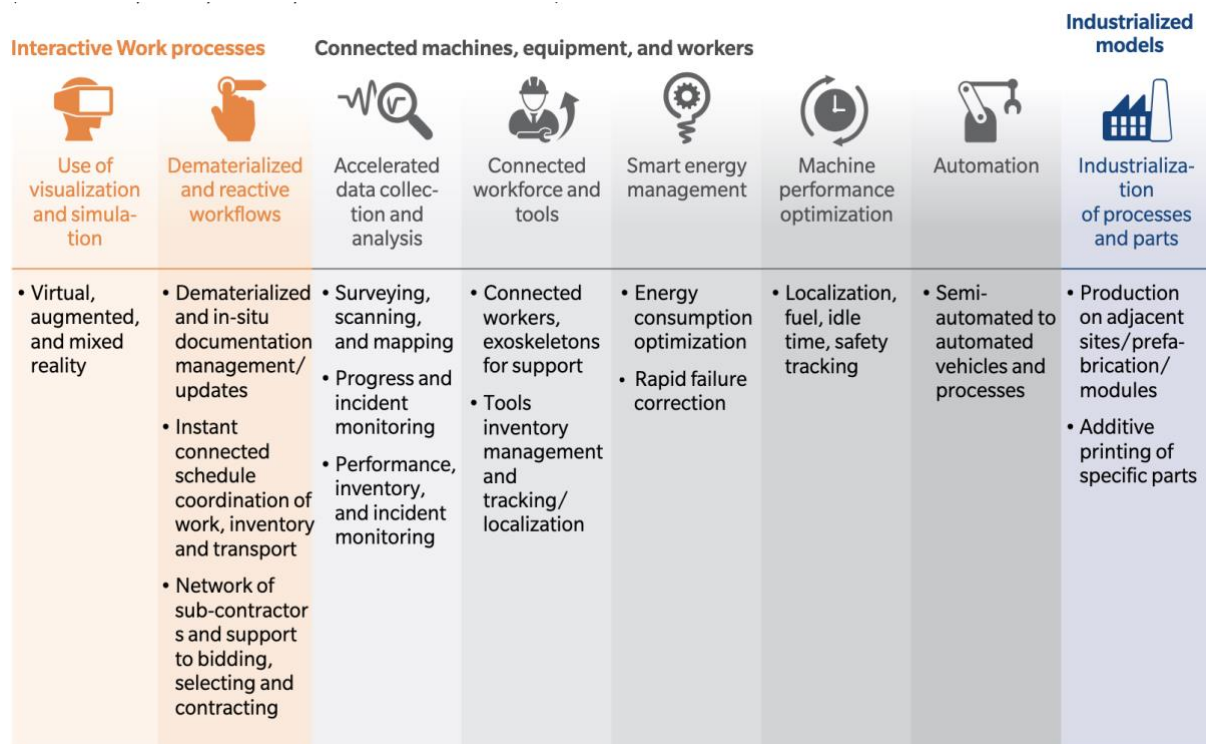


Figure 2. 5: Proponents of digitalisation in the process of digitalisation in the construction industry (Wyman, 2018)

These categorisations necessitate an amendment which is fundamental to the construction industry, especially when adopted across different project locations, sizes and financial capabilities. Furthermore, a great evaluation of the different practices in the construction industry also needs to be included in the categorisation. This is not to overlook the strides already made in the use of BIM, which is the primary digital tool in the South African construction industry (Maskuriy *et al.*, 2019), according to a relationship between innovative tool, intended function and the effect on the industry. This is expressed in Figure 2.5, where interactive work processes, connected machines, equipment and workers, as well as industrialised models, reinforce this. However, this suggests that an extreme exclusion of other tools is less explored through lack of access, procurement processes, and the inability of the industry to empirically research their effect and limitation. In conducting an extensive literature review, a set of tools currently in circulation in the South African construction industry was compiled, which is presented in Table 2.2. These factors contribute to the main research objective of this study, in that an interrogation of the familiarity of these tools and software is the premise of the inquiry among industry professionals. This list expands on the assertion by Wyman (2018) expressing a lack of standardisation and commitment to developing a framework and specifying available tools.

Table 2.2 presents a comprehensive overview of the critical digital technologies identified as essential drivers of construction productivity enhancement. The table highlights technologies that have demonstrated significant potential to improve efficiency, project delivery, resource management, and overall industry performance. However, among the technologies selected for the South African construction industry, existing research remains relatively limited and fragmented, indicating a marginal level of scholarly investigation within the local context. This research gap underscores the need for a more detailed and systematic examination of these technologies.

Table 2. 2: Various technological tools identified through the synthesis of literature.

Identified digital technology.	(Wang <i>et al.</i> , 2020).	(Maskuriy <i>et al.</i> , 2019).	(Goralski and Tan, 2020).	(Mahajan, 2021).	(Papulová <i>et al.</i> , 2022)	(Berlak <i>et al.</i> , 2021).	(Nasserddine <i>et al.</i> , 2022)	(Barlish and Sullivan, 2012)
Augmented Reality	X	X	X				X	
Building Information Software (BIM	X	X		X	X	X		X
Information and Communication Technology (ICT)	X				X			
Web Based Project Management (WBPM)		X						
Big Data and Analytics	X							
Internet of Things (IoT	X		X		X			
Digital Twins		X						
Production Robots (Robotics)	X	X	X		X	X		
3D Printing Machines	X	X			X	X		
Drones / Scanning Drones				X				
Virtual Reality	X							
Modular Construction					X			
Mobile Devices (smart and handheld devices)		X						
Blue Beam Software				X				X
Cloud Computing		X						
Virtual Prototyping	X							
Wearable Device (such as motion sensors and digital transmitters)	X		X					
Wireless Sensor Network (WSN)	X			X				

Consequently, this study seeks to comprehensively explore their adoption, implementation, challenges, and productivity implications within South Africa construction industry.

2.9 Barriers to the implementation of digital technologies in the Construction Industry

The construction industry ranks amongst the largest industries in the world (Barbosa, Woetzel and Mischke, 2017; Goubran, 2019; El Asmar *et al.*, 2021; Myers, 2022). However, the industry remains least digitalised (IDC, 2020; Ribeirinho *et al.*, 2020; Berlak *et al.*, 2021). Amidst the advocacy for digital adoption, there are embedded challenges within the construction industry as opposed to industries such as automation, banking, agriculture, medical fraternity and education (Boulle *et al.*, 2019; Smidt and Jokonya, 2022). There are unique obstructions specific to the construction industry (Ikuabe *et al.*, 2020; Aghimien *et al.*, 2021; Siddiqui, 2022). Some of these include the lack of knowledge, fragmentation of construction processes and systems, the capacity to streamline project processes autonomously, as well as the aversion of stakeholder commitment to digitise due to uncertainty (Smidt and Jokonya, 2022). These observations are remiss of the capability and infrastructure eminent to the industry in its operation and governance. Additionally, these assertions are not specific to the scope and conduct of the South African construction industry.

An expansion of this assertion is made by IDC (2020) in stating that digitalisation capabilities, which are pertinent to the reshaping of the construction business and technological expertise, should be adopted by any organisation aiming at increasing productivity. It follows that an organisation has to aim developing a well-defined framework of adoption which allows them to embed digitalisation across their operations (IDC, 2020; Papadonikolaki *et al.*, 2020; Ribeirinho *et al.*, 2020). Industrial Development Corporation IDC (2020) asserts that 52% of global construction companies have reached an impasse, as they do not have the capabilities and skill set to advance to more complex adoption and utilisation of digital technologies. However, it remains unclear what the hindering factors are. Aghimien *et al.* (2022) identifies some barriers that impede the adoption of digital technologies in the construction industry. Table 2.3 presents a synthesised list of barriers perceived to be major hindrances.

The fear of organisations being overly reliant on digitalisation across their tendering process and production phase is considered a significant barrier (Sacks and Barak, 2010). This observation is crucial, and unlike other industries such as banking, agriculture and education, it has the potential to cripple the production line and create cost overruns and time overruns on construction projects if not well executed. This over-reliance presents uncertain risks,

especially in South Africa, where many of the digital systems are still heavily reliant on the main grid supply of energy (ESKOM) (Aghimien *et al.*, 2022). This risk is associated with recurrent power outages, which may result in frequent malfunctions of technologies deployed on projects due to an inconsistent power supply. While the relationship between these factors is plausible, the discussion lacks contextual positioning within the broader framework, as it does not explicitly establish a correlation with overall construction productivity.

Table 2. 3: Identified barriers to the implementation of digital technologies on Construction Projects in South Africa.

Identified Digitalisation Barrier	(García de Soto <i>et al.</i> , 2022)	(Berlak <i>et al.</i> , 2021)	(Smidt and Jokonya, 2022)	(Demirkesen and Tezel, 2022)	(Loraine and Williams, 2000)	(Chen <i>et al.</i> , 2022)
The lack of skills across professionals			X	X		X
No training and knowledge of digital technologies						X
Fragmentation of the construction process.	X	X		X		
Resources to pay for digital technologies (software for a digital environment)		X	X	X	X	
Aversion of stakeholders				X		X
Uncertainty of utility of digital technologies	X	X		X		
Cybersecurity threat.	X					
Lack of investment in the use of digital technologies by both government and private sector	X		X	X	X	
Complexity of the construction project	X	X				X
Lack of Technical abilities to operate digital technologies (software)			X			X
The expense and cumulative operation costs to the organisation.		X	X	X		

A recurrent barrier dominant across literature is resistance from management (Demirkesen and Tezel, 2022). This resistance to changing the nature and operation is an impediment to fast-tracking the industry to levels its contemporaries are already achieving (Barbosa, Woetzel and Mischke, 2017; Aghimien *et al.*, 2022; Demirkesen and Tezel, 2022). It is this impediment that stagnates the industry and further provides no alternatives to the eradication of cost and time overruns (IDC, 2020; Sutherland, 2020). This aversion to change can be expanded to include the traditional nature of the construction industry. The industry is notoriously known to operate using brick and mortar. However, this does not preclude the industry from continuously finding other methods to improve operations and project productivity. Loraine and Williams (2000)

encapsulate this as the evidenced lack of continuous improvement by the industry, and as a result, this also forms part of the significant challenges in digital adoption.

The lack of financial investment in the procurement of digital technologies, the obtaining of licences for software, and the training of the workforce in the utilisation of such technologies and software is another barrier (Loraine and Williams, 2000; Boulle *et al.*, 2019; Chen *et al.*, 2022; Demirkesen and Tezel, 2022; Smidt and Jokonya, 2022). It is not evident the degree to which cost (or investment) impacts digital adoption. It is, however, expressed that from a cost perspective, the maintenance, training and hiring of specialists to operate digital tools in the construction industry is exorbitant (Alaloul *et al.*, 2020; Leung *et al.*, 2024). From an investment perspective, investors have an apprehension about investing in digital tools as the lack of guarantee that there will be a return on the investments is not quantifiable (Demirkesen and Tezel, 2022). While cost and investment consistently improve digitalisation, the structural positioning and organisational impact, is not exhaustively discussed. In lieu of the concept and hypothesis of the research, the predominant question “*How are construction organisations responding to this?*”, still remains central to this research and requires inquiry.

Maskuriy *et al.* (2019) states that two aspects of an organisation are intrinsic to lack of digitisation across the construction industry. These are the lack of capacity and streamlined strategy of operation. The first aspect is capacity building. In this argument, Maskuriy *et al.* (2019) argues that the construction industry comprises of various stages from inception through to completion of the project. As a result, various stages of the process can greatly benefit from intensive research in how the adoption of digital technology can improve the process and this is not limited to tendering, design and amalgamation of the various stakeholders and their contribution to the project. In this manner, the capacity to identify areas that are obsolete to the project can easily be identified and removed. Similarly, areas of a project under which maximisation of profit, efficiency and cost savings, can easily be enhanced for efficient project productivity (Oesterreich and Teuteberg, 2016; Maskuriy *et al.*, 2019; Chen *et al.*, 2022). The second aspect raised by Maskuriy *et al.* (2019) in the need for research and development is the industry’s capacity to expand and inadvertently contribute significantly to the GDP and job creation. The argument raised is that at various stages of the construction project, a particular skillset is required for the successful completion of the element of the job. As a result, a full knowledge of the available digital technologies in use in the construction industry, this could

create a better streamlined work schedule (Park, 2006; Aghimien *et al.*, 2018a; Petrov and Hakimov, 2019). Moreover, this affords all the individuals on the project to specialise in the operation of a particular digital tool, the skill of which could easily be applied to any project that digitalises its operations. Furthermore, this allows a larger populous of the unemployed individuals to specifically specialise on a particular technology and as a result curb the unemployment rate in South Africa (StatsSA, 2022). This postulation however relies heavily on the penchant of both private and public sector to invest in research and development. As it currently stands, literature does not have evidence of this being the case and as a result it is still a standing challenge in the construction industry (Aghimien *et al.*, 2018a; IDC, 2020).

Another challenge facing the ease of adoption and implementation of digital technologies in the construction industry is the fragmentation evidenced across the industry (Ofori *et al.*, 1996b; Meintjes *et al.*, 2007; Soekiman *et al.*, 2011; Demirkesen and Tezel, 2022). The development of any project relies on specific conditions, specifications and combinations and permutations of teams in order to complete the project; as a result, one project varies from the other. An intrinsic dynamism exists across projects which give rise to a specific circumstance-based solution to anything occurring on that particular project (Meintjes *et al.*, 2007; Curry, 2012). It is the prevalence of this difference across projects that creates a disjoint in the stakeholders, contractors, investors and clients from contriving a singular policy which can be adopted across all projects. It can be argued that during the design stages, the utilisation of BIM aids in allowing all the design professions (professional team) to work on the design of the structure at one time, even though they may not be in the same physical location (Barlish and Sullivan, 2012). However, this forms a marginal proponent of a large process, and as a result, this proposition cannot be perceived to be a definitive standard. This is neither to negate nor to invalidate the progress made in the initial stages of the development of the BIM solution. However, a larger portion of a construction project happens on site (in an external dynamic environment) through which feasible and tangible technological solutions could better necessitate the desired output (Barlish and Sullivan, 2012; Maskuriy *et al.*, 2019; Demirkesen and Tezel, 2022). In summation, Demirkesen and Tezel (2022) asserts that the fragmented nature of the construction industry is a direct cause of the industry's inability to adopt digital technologies. Furthermore, they additionally attribute this to the dynamism with which construction projects are constructed (Demirkesen and Tezel, 2022; van Wyk *et al.*, 2024b). The lack of standardisation across the construction industry is part of the reason the pace of

digital adoption is slow (Olatunji *et al.*, 2017; Chen *et al.*, 2022; van Wyk *et al.*, 2024b). The construction industry, unlike its contemporary industries, has struggled for years with standardisation. This is due to variances in project types. Moreover, the industry does not have a monolith of how a particular design is supposed to be carried out, how a project is constructed or what procurement strategy better suits a particular project type. Additionally, there is a variety of building and civil projects that even though they may use a particular building contract such as New Engineering Contract (NEC), The international Federation of Consulting Engineers (FIDIC) or Joint Building Contracts Committee (JBCC), the scope and scale of the project varies (Barbosa, Woetzel, Mischke, *et al.*, 2017; Chen *et al.*, 2022). Standardisation as an impediment to the adoption and uptake of digital technologies which cannot be viewed in isolation from the amount of work needed from a governance and legislative part of the government in order to implement this and make it a standard (Demirkesen and Tezel, 2022). This is congruent with the findings from the study conducted by Ikuabe *et al.* (2020) in postulating that the absence of a legal interrogation regarding standardising the construction industry is part of the challenges encountered. Moreover, this legal interrogation forms the nexus between legislation and government which carries significant influence in changing the landscape and operation of the construction industry, particularly in the current digital climate where Industry 4.0 is the disruptor (Maskuriy *et al.*, 2019; Ikuabe *et al.*, 2020; Aghimien *et al.*, 2021).

Another challenge facing the industry is the lack of a skilled labour force (Barbosa, Woetzel and Mischke, 2017; cidb, 2017; Demirkesen and Tezel, 2022). The advent of new digital technologies across construction projects requires a certain level of skillset that, over the years, has been diminishing (Barbosa, Woetzel and Mischke, 2017). The construction industry comprises many levels of qualified personnel, ranging from the CEO, Project manager, construction manager and through to labourers. All of these professionals on the construction project have different types of skill sets and a certain level of education. Notwithstanding that, digital technologies, especially when viewed in relation to the intricate and complex work these devices are procured to be utilised for, can require meticulous methods to operate, thus necessitating a specialised skillset (Aghimien *et al.*, 2021; Demirkesen and Tezel, 2022). This point is expanded further by Allmon *et al.* (2000) in postulating that part of the reason the necessary skillset is not as readily available in the construction industry to meet the demand and the trajectory of the migration to digital operations, is largely due to the complex and the

non-standardisation in the industry. This is further reinforced by Chen *et al.* (2022) when asserting the same sentiment as being an impediment to the uptake of digital technologies in the construction industry. These assertions demonstrate limited relevance to the South African construction industry. Although the discussion of skillsets indicates a deficiency, it does not explicitly identify a particular profession or segment within the construction sector to which this shortfall applies.

The challenges expressed are not an exhaustive array of all the factors that impede the digitisation of the construction industry. There is a myriad of other factors that also significantly present challenges. Some of these challenges include legal rigidity (Berger, 2016; Aghimien *et al.*, 2021). This is largely evidenced by the lack of standard regulatory amendments which have not been enacted in any of the building contracts (NEC, JBCC and FIDIC). These contracts have no provision for the utilisation of digital technologies. Furthermore, the design of contract data and tendering processes has not explicitly incorporated or made provision for technological uptake. Unlike the enacted EU directive which makes it mandatory that for government contracts to be awarded, 50% of the project must use BIM systems (Berger, 2016; Berlak *et al.*, 2021). The same position was also adopted by the German Federal Ministry of Transport and Digital Infrastructure that legislatively, a significant portion of the project awarded must have digitalised systems in the operations and construction (Berger, 2016; Berlak *et al.*, 2021). This has not been the case in the South African construction industry and many other countries on the African continent. This commands and interrogative approach as it presents a gap not empirically or theoretically adequately researched within the South African construction industry.

There are concerns regarding cybersecurity amidst digitising (Aghimien *et al.*, 2018a; Aghimien *et al.*, 2021). Some organisations reported to have their own independent intranet systems which store the company's reserves of data spanning decades. However, this data is only accessed and utilised largely in the event that an individual requesting such use is on the same internet server. Furthermore, the utilisation and retrieval of such data may present a threat to security in the event of having multiple internet connections (García de Soto *et al.*, 2022). The proper handling of contract data is presented as another concern. Organisations in the construction industry present a general reluctance to the adoption of digital technologies, in that there is uncertainty pertaining to security measures around the retrieval of data remotely

(Aghimien *et al.*, 2018a; Ikuabe *et al.*, 2020; Chen *et al.*, 2022; García de Soto *et al.*, 2022). This presents a gap and conceptual lack of exploration as this threat has the propensity to anchor a theoretical inquiry unevenly in the literary position or further express an unevaluated premise in research that must be synthesised.

2.10 External factors impacting levels of construction productivity on projects

An extensive body of literature exists on the fundamental factors that affect productivity levels in the construction industry. These factors spans from those which affect the construction industry from the inception stages of the project when the conceptualisation of an idea is being developed (Khan and Ajmal, 2015). Furthermore, these factors further extends to those that intrinsically affect the project development or construction phase of a development (Kaming *et al.*, 1997; Enshassi *et al.*, 2009; Jang *et al.*, 2011; Nawi *et al.*, 2014; Barbosa, Woetzel and Mischke, 2017; Almamlook *et al.*, 2020; Adebawale and Agumba, 2023). Notwithstanding this, these factors are also evident, and their magnitude of effect is reflected in the project life-cycle stage. Furthermore, scholars have raised significant concerns regarding these factors, which are indicative of the disenfranchisement of construction processes and the widely discussed fragmentation within the industry. As a result, this study positions itself as a nexus between the digital adoption of varying technologies and the expended levels of construction productivity or the project performance. This allows the study to synthesise and observe the impacts (if any) of the direction in which adoption improves or deters project productivity when mediated by digital technologies.

A critical elements in the production or development of a project, is the productivity of labour which leads to overall project productivity when administered and configured appropriately as per the project demands (Khan and Ajmal, 2015; Sui Pheng *et al.*, 2019). There are factors that are endemic to the construction environment that affect the ability of labourers to maintain productivity, optimum project delivery. A substantial body of research has been conducted on various construction developments, including infrastructure projects, residential and commercial buildings, high-end developments, and road construction. A shared characteristic across these building types, construction processes, and material procurement methods is that they influence projects in a comparable manner. Specifically, their effects often manifest as increased project costs and schedule overruns, and in some instances, compromised project

quality (Kadir *et al.*, 2005; Soekiman *et al.*, 2011; cidb, 2015). Jang *et al.* (2011) argue that there are four core clusters of factors which affect construction productivity. However, this assertion is further supported by Jang *et al.* (2011) postulating that these four clusters of factors are significant to project development, and as a result, not to be omitted at any stage of a project development (Olomolaiye *et al.*, 1987; Makulsawatudom *et al.*, 2004; Enshassi *et al.*, 2009; Hughes and Thorpe, 2014; Jarkas, 2015). Notwithstanding that, the consistent occurrence of these factors in the disruption of the construction process has not been resolved, and this necessitates an analysis of their impact on project productivity when moderated through the use of digital tools (Barbosa, Woetzel and Mischke, 2017; Almamlook *et al.*, 2020; Adebowale and Agumba, 2023). The dissemination of these factors is categorised into three categories as presented in Table 2.4. These are environmental, organisational/construction firm and technical factors.

Table 2. 4: Categories of factors affecting project productivity.

Category	Factors
Environmental factors Cite: (Kaming <i>et al.</i> , 1997; Sweis, 2000; Makulsawatudom <i>et al.</i> , 2004; Park, 2006; Enshassi <i>et al.</i> , 2009; Hughes and Thorpe, 2014; Jarkas, 2015; Lefoka, 2019; Argyroudis <i>et al.</i> , 2022)	Inclement weather (rain/cold/heat)
	Unexpected site ground conditions
	Site location/environment
	Lack of experience amongst workers
	Poor site supervision
	Lack of tools and equipment
Organisational/Construction firm factors Cite: (Kaming <i>et al.</i> , 1997; Sweis, 2000; Makulsawatudom <i>et al.</i> , 2004; Park, 2006; Enshassi <i>et al.</i> , 2009; Hughes and Thorpe, 2014; Jarkas, 2015; Lefoka, 2019; Durdyev and Hosseini, 2020).	Economic changes (change in VAT, inflation, and foreign exchange rates)
	Fluctuations in material/equipment prices
	Change in government legislature/policy
	Delays in payment of labour
	Non-payment of labour
	Inexperienced supervisors
	Changes in management structure
	Mismanagement of resources on site
	Shortage of labour/manpower
Technical factors Cite: (Kaming <i>et al.</i> , 1997; Sweis, 2000; Makulsawatudom <i>et al.</i> , 2004; Park, 2006; Enshassi <i>et al.</i> , 2009; Hughes and Thorpe, 2014; Jarkas, 2015; Lefoka, 2019; Casini, 2021).	Poorly designed projects
	Incomplete drawings
	Methods of construction (prefabrication vs onsite)
	Inspection delays from engineers
	Change orders from the designers/consultants
	Poor co-ordination/planning of activities

	Rework due to poor quality
	Complexity of the project
	Buildability of the structure

2.10.1 Environmental Factors

In lieu of the significant contribution that the adoption and implementation of digital technologies have on the project productivity, external impact of environmental factors cannot be negated. The development of a construction project and the execution of the project schedule is dependent on the climatic conditions under which a project is being developed. In South Africa, the most northern part of the country experiences heavy rains during summer seasons and the adverse is true for the southern part of the country. This means that during these seasons, much of the formative trades of the project cannot be executed. Notwithstanding that, the implementation and use of digital tools become integral to the planning stage of a project. Moreover, when this is coupled with climatic forecasting sensors which work in synchrony with the adopted technological equipment of site such as 3D printing machine, the effect of weather condition can be prevented (Casini, 2021). Additionally, with the knowledge of the kind of climatic conditions expected over a particular area, some of the project activities can be carried out without detracting from the overall project success thus not negatively affecting the progress of the project and the success thereof.

Another environmental factor mostly neglected, however pertinent to the excavations stage of a project, is the unexpected site conditions. In some of the project developments, it happens that excavations are carried out without a proper and well-detailed feasibility study of the ground conditions (Makulsawatudom *et al.*, 2004; Adebowale and Agumba, 2023). Literature postulates that the degree of effect these unexpected ground conditions have, has the ability to increase the project cost and as a result, give rise to time delays. However, some of the mechanisations adopted in the construction industry such as VR and AR are built with sophisticated sensors which allows a full view and reporting of all the services, pipes as well as any other components in the ground (Nassereddine *et al.*, 2022). The advanced mechanics in modern technologies, allows the project manager to circumvent the effects timeously so as to not delay project initiation. The lack of adequate plant and equipment is one of the factors cited as the root cause of some delays which are experienced on projects (Argyroudis *et al.*, 2022). However, the implementation of digital technologies, as observed in other industries, have an innate function of being able s execute multiple tasks at once (Wyman, 2018;

Nassereddine *et al.*, 2022). The utilisation of robotics and off-site monitored plant and equipment provides this function in that their configuration are able to handle complexity, multiple-task function and output production (Navaratnam *et al.*, 2022; Adekunle *et al.*, 2023). The multifunctional capability is perceived as a salient attribute that significantly contributes to enhanced productivity in project execution. The responsibility to mechanise, forecast and circumvent the effects of environmental factors, is an objective of any organisation. However, this cannot be well implemented if the managerial and financial investment in technology is disregarded from the inception through to the life cycle of a project.

2.10.2 Organisational/Construction firm factors

Previous studies have stipulated that attempts to make digitisation mandatory across construction industry, is an adoption to fast-tracking mechanisation and doing away with traditional methods of construction (Berger, 2016; Degryse, 2016). An organisation's uptake to digitalisation and integrating software which aid in the management of projects, is important for the success of a project and subsequently, the profitability of an organisation (Maskuriy *et al.*, 2019). Countries such as China, Finland and some that are in the EU have leveraged on this in that they have a well-developed technological infrastructure, skilled and operators of advanced technological software and robotics. This is further fortified by investments from both government and private sector (Adekunle *et al.*, 2023). This ensures that in the event that the economic disruptions are encountered which affect the rate of exchange, buying power and inflation; these nations have the elasticity to keep operating and producing projects with minimal detractions.

In the case of South Africa, the lack of meritocracy, which led to a decline in strategic investment in the advancement of digital technologies, is considered a fundamental cause of the slow progress to adoption (van Wyk *et al.*, 2024b). Furthermore, when inflation rate or foreign exchange rates experiences market instability, this affects organisations which trade internationally, and across the construction industry, organisations which procure their resources internationally (Demirkesen and Tezel, 2022; Hwang *et al.*, 2022). This means that organisations in the construction sector aiming to advance project productivity through digitising are negatively affected (Von Broembsen *et al.*, 2005; Nassereddine *et al.*, 2022; Alwashah *et al.*, 2024).

A symbiotic relationship exists between fluctuations in material/equipment prices and the dynamism in economic changes. A subset of literature closely delineates the impact these economic changes have on equipment procurement prices. The assessment of this relationship is anchored in the financial capability of an organisation to maintain the buying power of the necessary digital plant and resources, devise a framework of operation when adopted on projects, and skillset training for the staff composition in utilising these tools. This enquiry is significant as it indicates the potential effect this has on the construction productivity (Makulsawatudom *et al.*, 2004; Enshassi *et al.*, 2009; Hughes and Thorpe, 2014; Paulmakesh and Makebo, 2022). In the event that there is any additional change in the material cost along the procurement chain, this can indicate an effect on the project profitability. It is thus argued that with the use of digital technologies, these economic changes can be identified on time and mitigated accordingly (Demirkesen and Tezel, 2022). Furthermore, it is purported that some of the critical elements considered during the tendering stages of a project, can be forecasted with the use of digital tools and as a result, prevent any eminent effect to the project and success thereof (Alwashah *et al.*, 2024).

Legislation plays a critical role in the adoption and implementation of digital technologies. This is due to the fact that some of the international economies are advanced and developed enough to enact policy that ensures standardisation and adherence to governing standards to the utilisation of digital tools in the construction industry (Demirkesen and Tezel, 2022). The same sentiment cannot be expressed about the South African construction industry. Fragmentation and lack of standardisation in the industry inhibits growth and creates a notable disparity across contractors, stakeholders and clientele in the industry. This factor does not entirely prohibit the industry from adopting digitalisation. However, the implementation thereof is largely attained by contractors that rank between 4-9 on the cidb registry particularly due to the financial leverage these companies have.

A fundamental requirement for any organisation and the personnel which are to utilise the prescribed kind or type of digital tools for the development of a project, is the knowledge, skill and understanding of the said kind of technology. One of the most significant factors cited in literature as having an impact on construction productivity across projects, is the lack of skill and knowledge of management evidenced across management and employees (Makulsawatudom *et al.*, 2004; Hughes and Thorpe, 2014). The level of productivity is significantly reduced mainly due to the fact that unskilled workers predominantly take longer

to satisfactorily complete tasks due to limited expertise and fundamental knowledge of the work. This further leads to both cost and time delays across the project and this occurrence fundamentally affects the profitability of the project (Sweis, 2000). Furthermore, depending on the building contract implemented on the project, significant penalties can be imposed on the contractor as a result of the use of workers that do not have the required skills to execute the work. Notwithstanding that, the workmanship of the labourers can evidently be seen in the errors which ultimately arise on the project and in some cases, require rework and making good the portions of the work not delivered according to the correct specifications to me addressed. Moreover, this further gives rise to another cost with regard to the increased material wastage (Enshassi *et al.*, 2009; Baloyi and Bekker, 2011). An extensive amount of training from organisations that implements digital software and tools is necessary for the success and profitability of a project. However, this can mean that an organisation must expend a significant amount of money to achieve that. Moreover, it is prudent that this endeavour is carried out before the start of a project as a preventative measure to exorbitant accumulation of errors on the project which ultimate lead to cost and time overruns (Mahamid, 2012).

2.10.3 Technical factors

A thorough analysis of factors impacting the productivity of a project from a design perspective is important so as to assess the degree and implication this has on the success of a project. The significance of the design stage of a construction project is crucial to project initiation. It is through the completion of this stage that a work breakdown structure and material procurement program can be developed. (Mahamid, 2013). As this can be done through completed structural, architectural and mechanical drawings, the requirement is that all stakeholders present their input in a master drawing. The inability of stakeholders to have completed drawings and necessary documentations at this stage, can negatively affect the productivity of a project (Alinaitwe *et al.*, 2007; Ebekoziem *et al.*, 2015; Abbasi *et al.*, 2020). This factor is central to the success of a project in that it advance all other activities associated with the feasibility of a project such as building up a bill of quantities (BOQ) for the project, drawing up a contract data, scheduling a work breakdown structure (WBS), site layout and composition of the various professionals needed to execute the project. This phenomenon is seen across the construction industry from a global perspective, through to the South African domain of the industry. However, instituting the implementation of digital technologies or software such as BIM to ensure the smooth and efficient completion of drawings can have significant positive effects on the project planning and design (Berger, 2016; Maskuriy *et al.*, 2019; IDC, 2020).

Additionally, in instances where one of the professional team members is not able to retrieve or complete a portion of their work, drawing due to the omission of a pertinent detail to the project, the software allows for an expedient mode in which such a detail is dispensed to the said professional for the design to be completed on time. Furthermore, another ingrained issue in delaying the project's completion is poorly designed drawings. This is mainly due to BIM's ability to process large amount of data through the process of exchange, reusing of the input information, and the speed of finalisation of a directive through the lifecycle of a building which is important during the design phase (Ham *et al.*, 2008).

There is no monotony across construction projects, and as a result, the levels of complexity vary from project to project (Durdyev and Hosseini, 2020). This is observed when differentiating projects by function, such as infrastructure projects or residential projects. The degree of complexity can expose the project and all personnel working on its development to adverse circumstances, necessitating intervention to mitigate their effects (Zhou *et al.*, 2014; Regona *et al.*, 2024). These can include managing a large team, the interconnectedness of various elements to bring the project to completion, or collaboration with experts who are specialised in trades that are not exclusively construction-related (Durdyev and Hosseini, 2020). The management of complexity enhanced and improved by skilled and precise application of tools that can help manage it. This may include using VR to assess the practicability of the project and drones to manage its development (Nassereddine *et al.*, 2022). In so doing, this can aid in the management of the project and mitigate any delays which can be envisaged from the onset of the project and create a quick turnaround loop for those inspections which can delay the project if not conducted on time (Makulsawatudom *et al.*, 2004; Mahamid, 2013; Durdyev and Hosseini, 2020).

The prescribed method of construction is considered a factor that affects productivity. In the past decades two distinct methods of construction are distinguished, and these are prefabrication and in-situ construction (Hughes and Thorpe, 2014; Lu *et al.*, 2021; Han *et al.*, 2022; Zhou *et al.*, 2023). These methods comprise their specific benefits and disadvantages, especially within the contexts in which they are adopted. Particularly with the onsite method where the level of quality control is often inconsistent which is the adverse for prefabrication. Notwithstanding that, these do not have an integral utilisation of digitalisation. Assessing and evaluating this through the perspective of digital disruption, stand to provide an outlook in how the methods respond to the adoption. Moreover, environmental factors such as change in

climatic conditions can be an impediment for some project. However, the use of robotics, 3D printing and drones can mitigate this effect and thus diminishing the differences in poor quality delivery of projects. The use of these tools however requires skill, knowledge and adequate training. As a result, large capital outlay to procure digital tools and equipment is significant.

2.11 Chapter Summary

This chapter reviewed literature relevant to the research objectives and questions by examining the evolution of industrial revolutions and their contributions to economic growth, productivity, and sustainable development. It highlighted the emergence and significance of the Fourth Industrial Revolution (4IR), particularly within the construction industry, and explored how technologies such as the Internet of Things (IoT), Building Information Modelling (BIM), Virtual Reality (VR), and Unmanned Aerial Vehicles (UAVs) support the achievement of Sustainable Development Goal 9 (SDG 9). The literature revealed that, despite rapid digital transformation in other sectors, the construction industry has been slow to adopt digital technologies. Key barriers include financial constraints, uncertainty regarding returns on investment, resistance to change, industry fragmentation, lack of standardisation, and inadequate legislative support. While digital frameworks have been proposed, their implementation remains challenging for small and medium-sized enterprises with limited resources. The chapter also examined the benefits of digitalisation, including improved productivity and operational efficiency, drawing comparisons with more digitally advanced industries. Factors enabling and hindering adoption were assessed alongside hardware- and software-based digital tools currently used globally and within South Africa. Construction productivity and its measurement parameters were further explored. Finally, external factors influencing project performance, including environmental, organisational, technical, and social dimensions, were examined. The literature review revealed a significant research gap concerning the interplay between digital tool adoption, productivity outcomes, and external contextual factors. Addressing this gap constitutes the primary focus of the present study.

CHAPTER THREE: THEORETICAL AND CONCEPTUAL FRAMEWORK

3.1 Introduction

This chapter provides a synthesis and the overarching framework for this study. Moreover, the core focus of this chapter is to evaluate and assess theories predominantly used to assess and evaluate construction productivity. Additionally, these theories provide the conceptual basis for explaining how the moderator, digital technologies (digitalisation), influences construction productivity. A theoretical framework is critical for any research study as this sets a clear and valid framework that justifies the significance of undertaking the research study and supports the conceptualisation of the research framework. In the conception of the theoretical framework, a set of theories have been adopted to underpin the study. The theories probed and adopted in the conceptualisation of the framework for this study were Disruptive Innovation Theory (DIT), Configuration Theory, Chaos Theory, and Technology Adoption Model (TAM). This chapter evaluates these theories and how they have been used in other studies, and how they can contribute to the development of a conceptual framework for this study. These theories are further correlated to the objectives of the research and building of the research hypothesis.

3.2 Definition and significance of theory in research

A research study that does not clearly distinguish between the concepts of theory, theoretical framework, and conceptual framework risks compromising its objectivity and methodological rigor, particularly because these terms are frequently used interchangeably despite their distinct meanings and functions within the research process (Rocco and Plakhotnik, 2009; Kivunja, 2018; Varpio *et al.*, 2020). This is due to the lack of not properly drawing the distinctions across these three terms which means varying concepts in as much as research is concerned (Creswell, 1996; Creswell, 2009; Varpio *et al.*, 2020). The term “theory” ought to not be conflated with the term “theoretical framework” as the two are completely different from a research perspective, particularly objective research that elucidate a generalizable outcome (Varpio *et al.*, 2020). According to Varpio *et al.* (2020) and Kivunja (2018) theory can be understood as a network of propositions which are logically related and expressing the relationships or correlations across varying constructs of research. The definition is broadened further in that a theory can be perceived as an intellectual narrative that shows and draws the linkage across

multiple concepts, paradigms, causation and effect (Varpio *et al.*, 2020). The legitimacy and reliability of a theory is largely dependent on the amount of data which supports it. Moreover, the more a particular set of data supports the theory, the stronger the efficacy of the theory becomes (Varpio *et al.*, 2020). This assertion is purported by Kivunja (2018) in postulating that theory emerges from a prolonged repetitive process of research that uses empirical data through either an inductive or deductive analysis, which gives theory its rigor and reliability of use.

It can be inferred from the aforementioned definition that one of the fundamental objectives of a theory is to identify relationships and establish generalizations regarding outcomes across different levels or dimensions of perception (Kivunja, 2018; Varpio *et al.*, 2020). As a result, contingent on this contextualisation is a further understanding of the varying levels across which a theory is used for applicability. Neuman (1997) expands on the three tiers, which increases the depth and knowledge of theoretical perception. These three tiers are the micro-level, meso-level and macro-level. Theories that explain the relationship among individuals are termed micro-level theories. Theories that explain the relationships or interactions amongst groups at an institutional level (such as a construction organisational level) are termed meso-level theories. And lastly, theories that explains and fully elaborates on the aggregated level such as the evaluation of the impacts of digital technologies across varying organisations (provinces and countries), are termed macro-level theories (Neuman, 1997; Creswell, 2009; Kivunja and Kuyini, 2017; Kivunja, 2018). As a result, since the study models the adoption of digital technologies across various construction organisations (and projects) in South Africa, the theoretical conception/perception adopted is macro-level. Additionally, this is due to the evaluation of relationships which are to be tested in relation to project productivity when utilizing digital tools.

3.3 Framing and defining theoretical framework for the study

It further follows that a thorough understanding of what constitutes a theoretical framework is defined and contextualised. A theoretical framework is an overarching set of theories which have been tested and validated across varying disciplines. However, central to the researcher's interrogation of the research question is a set or list of selected theories which are used as building blocks to shape the hypothesis and conceptual framework for the study (Russell, 1914; Victora *et al.*, 1997; Creswell, 2009; Rocco and Plakhotnik, 2009; Kivunja, 2018; Varpio *et*

al., 2020).

A substantial body of literature presents numerous theories that provide a robust framework for understanding the application and adoption of digital technologies within the construction industry. Notwithstanding that, the application of digital technologies in the construction industry as a mediator to assess levels of project productivity comprises a dearth literature, particularly in the South African construction industry. However, the assertion that is made by Berger (2016) is that the application of a singular theory to synthesise a generalisable and objective conclusion, circumvents a holistic overview of the relationship digitalisation technologies has on project productivity. Additionally, this is suggested to impede the study from having a vast and acceptable generalisability of the results (Andersen, 1997; Berger, 2016; Sveikauskas *et al.*, 2016).

This study adopted a theoretical framework based on the multiple theory approach in order to leverage the complexity and anchor the conceptual framework in theories with substantive significance. This is because the research objectives and question necessitate rigorous and in-depth analysis. Moreover, this is due to the layered nature of the study in that the relationship between productivity and elements of digitalisation is of inquiry (Varpio *et al.*, 2020), which both are pertinent in addressing the research objectives, answering the research question and developing a logical conceptual framework (Victora *et al.*, 1997; Gray and Rumpe, 2015; Varpio *et al.*, 2020). The theories adopted in the development of the conceptual framework are Disruptive Innovation Theory (DIT), Configuration Theory, Chaos Theory, and the Technology Adoption Model (TAM) Theory.

3.3.1 Disruptive Innovation Theory (DIT)

Disruption innovation theory is classified as a set of systems, technologies and methods of a modern operation which offers various values to the client/consumer which is superior to the mainstream utilization of traditional methods (Christensen, 1997). To contextualize the evolution of innovation (particularly disruptive phases across decades), Christensen (1997) drew a time lapse of what necessitated an interrogation of the various innovation technologies as well as their contributions to many economic fields, including the construction industry, across the decades since the 1940s.

This theory is fundamentally used in research for the purpose of understanding the efficacy, productivity output and value add to construction projects (Dan and Chieh, 2008). Christensen (1997) further expands on this definition by postulating that the disruptive innovation theory comprises of two fundamental classes of significance, which must be assessed cautiously, before they are utilized and integrated in the development of digital technologies and digital systems at the organisational and industry level. According to (Christensen, 2015), these classes are categorised in two subsets, the first being: revolutionary, discontinuous, radical and step-function technologies or digital systems (Christensen, 1997). The second subset of digitalisation technologies are described as evolutionary, continuous, incremental or nuts-and-bolts. Disruptive innovation theory posits that the application of digitalisation in the design, construction and management of a construction project and prediction of the levels of expected productivity, can vastly improve organizational output. This reaction assumes that when digitalisation is adopted on a construction projects, optimal levels of productivity output can be achieved (Christensen, 1997; Schober *et al.*, 2016).

3.3.2 Configuration theory

An extension of (DIT) is configuration theory, which also serves as a foundational basis for the synthesis of this study's conceptual framework. Configuration theory is defined as the identification of patterns and combinations of digital tools with external variables, and assessing how the interplay affects the determined outcome of a project (Rihoux and Ragin, 2008; Mikalef *et al.*, 2015). This definition is expanded further by Fiss (2007) in positing that configuration theory provides an all-inclusive study that assesses the interconnectedness of the digital technologies in a dynamic and ever-changing environment, to clearly evaluate the productivity of a project. Since the objective of this study is the analysis of the application of digital tools to observe the impact on productivity, this theory fits into the development of the study's conceptual framework.

In studies applying this theory, the primary objective has been to adopt a comprehensive perspective that simultaneously examines variations in variables across predefined levels of construction productivity and their corresponding effects on measured output (Rihoux and Ragin, 2008). Since this is the basis of this study, this holistic view will aid in assessing the configuration of the technologies used and what levels are observed in relation to construction productivity.

3.3.3 Chaos Theory

Chaos theory is another theory that underpins the synthesis and the development of the conceptual framework for this study. The fundamental principle of chaos theory is to provide the researcher a perspective of how uncertainty and complexity are managed across the construction industry and organisational planning systems. Furthermore, this theory is used in the build environment research due to the non-linear nature of the industry (Singh and Singh, 2002; Lu *et al.*, 2010). Chaos theory is entrenched in the unpredictable and turbulent nature of a construction development and aids in the mitigating or strategic endeavours to neutralize or circumvent the impact incurred (Singh and Singh, 2002).

The application of this theory is predominantly observed in related scientific disciplines such as manufacturing, supply chain management, logistics, and systems operations, where a disruption in any single component of the production system may generate cascading effects across the entire operational network (Singh and Singh, 2002). Notwithstanding that, this theory allows a rapid identification of the disruption in the system and mitigates the impacts or effects before a ripple effect can disrupt the productivity and efficiency in the operations or production (Ayers, 1997). This is particularly due to the fact that the study's focal concentration is to investigate how digital technologies, when used to moderate construction processes, impacts construction productivity. Additionally, the study aims to assess the relation between these technologies and the kind of productivity generated on projects, in determining optimal function of construction project, organisation or industry.

3.3.4 Technology Adoption Model (TAM)

A technology adoption model is a theory that is embedded in the modelling and building a framework around how users of digital technologies acclimatize and come to accept the technology implemented (Lai, 2017). TAM posits that users of digital technologies hold underlying beliefs and perceptions regarding the perceived usefulness and ease of use of such technologies, which in turn influence their adoption and usage behaviour. Furthermore, the efficacy and the usability of these digital technologies affect the attitude and perceptions of users to either adopt or refute its applicability in construction processes (Calantone *et al.*, 2006; Lai, 2017).

The study lands itself in the adoption of digital technologies as a mediator to construction productivity. Thus, the principal strengths of this theory which are user adoptability and functional integration within construction systems, will contribute to the development of the study's conceptual framework satisfactorily.

3.3.5 Correlation of theories to research question and hypotheses

The rationale for the selection of these theories rests in their capabilities to cut through multiple levels of the research questions and objectives. As stipulated in the objectives, the assessment and identification of digital tools is paramount to the research. Additionally, the levels of expertise, capabilities and readiness of the South African construction industry is as equally significant. Disruptive Innovation Theory addresses this in that it is posited to be evolutionary, continuous, incremental and radical in nature. It is these precise qualities that in evaluating the digital tools, positioning where they merge to advance incremental levels of construction productivity, this theory aid in the analysis observed. Moreover, configuration theory is anchored around pattern identification and layering of various digital tools which correlate to specific sections of the construction work. This quality provides the research with a direct understanding of the kinds of skills required at each level of a construction project. This is further inculcated in the two types of datasets the study envisages to collect (quantitative and qualitative). Lastly, this phenomenon allows an observable interplay in the relation of the variables to the levels of productivity observed when the inclusion of digital tools is used to moderate this productivity.

The correlation between the research objectives and chaos theory is directly related to the impact of digital technologies adopted and the gap in the productivity between traditional approaches and that observed when digital forms of construction are used as moderators. This is primarily related to the theory's uncertainty and complexity. When varying forms of technologies are adopted, a change is observed in the line of production and sequencing of the works. Moreover, when environmental, technical and managerial components are assessed. It is for this rationale that this theory fits the objectives and synthesis of the research. Lastly, the research hypotheses are observed through the lens of TAM in that perceptions are both tested and evaluated. Furthermore, the formulation of the models allows the study to analyse this across quantitative and the qualitative data analysed. It is for this rationale that these theories (Disruptive Innovation Theory, Configuration Theory, Chaos Theory and TAM) are selected

and adopted for this study. Table 3.1 presents the split and relation of the constructs stated theories and the envisages hypotheses upon which they are selected for with regard to testing. Additionally, the table presents the various constructs which will be interrogated under the lenses of the relationship between hypotheses and theories.

Table 3. 1: Theory-construct-hypothesis mapping.

Hypothesis	Constructs	Theory
H1	Digitalisation and Productivity	Disruptive Innovation/Configuration/TAM
H2	Digitalisation and Contextual factors (Environmental/Organisational and Technical factors)	Disruptive Innovation/Configuration/Chaos
H3	Digitalisation and Skill	Disruptive Innovation/Configuration/TAM/Chaos

3.4 Conceptual Framework

Addressing the research objectives and subsequently answering the research question, commands a systematic and well thought through structure to elicit a full understanding and guide to do so. This section details the framing of the conceptual framework, and the various related concepts interrogated to synthesise this. A conceptual framework is not a monolithic prototype that can be duplicated for each study and applied as such. However, it is a fundamental justification for a study to be undertaken (Varpio *et al.*, 2020). A pretext to this assertion is made by Shikalepo (2020) in citing that many attempts have been made by various scholars to contrive a perfect definition of a conceptual framework and these attempts have not always yielded a universal definition due to the varying nature of research and their focal concentration of scholarly fields (Victora *et al.*, 1997; Creswell, 2009; Kivunja and Kuyini, 2017; Kivunja, 2018; Varpio *et al.*, 2020).

A notable point of departure elucidated by Kivunja (2018) is that a conceptual framework developed for the study cannot be developed as a framing that is mutually exclusive from the objective of the research, the need for the research, the plan for the research, the identified gaps in the need for the particular research; as well as the methods and techniques of the data analysis. Furthermore, this is asserted by Thomas (2012) in positing that an intense interrogation and analysis of literature provides a founding ground for a well-structured conceptual framework which inadvertently acts as a metacognitive, reflective and equipped operational structure of a research study (Kivunja, 2018).

The development of a conceptual framework for this study and its parameters is adopted from the Varpio *et al.* (2020) model of conception for theory, theoretical framework and conceptual framework as evidenced in Figure 2.1. An extant synthesis of literature was conducted thorough a rigorous analysis of already existing body of work. Additionally, this was further streamlined by the keywords allocated to this study. As illustrated in Figure 2.1 and discussed above, the conceptual framework is grounded in the theoretical framework underpinning this study. It is anchored in the selected theories, which collectively provide the analytical foundation for interpreting, analysing, and reporting the research findings. The integration of these theories facilitates a comprehensive and holistic understanding of the phenomenon under investigation. Additionally, the formulation of the research hypothesis and its effectiveness in addressing the central focus of the study were evaluated, particularly with regard to its ability to answer the research question (Varpio *et al.*, 2020).

The conceptual framework of a study is largely rooted in the theories interrogated and identified as being central to the building of a pragmatic foundation in addressing the research objectives and answering the research question (Lederman and Lederman, 2015). Additionally, it is imperative that the adopted theories are cantered around the adoption, application, and utilisation of digital technologies/innovative technologies in the construction industry, to illustrate how the construction productivity is affected. Moreover, this strategic framework is anchored in the explicit identification of the underlying theories, as well as the key constructs to be empirically tested and those to be examined through theoretical analysis. Lastly, the strategic component anchors the research in the inquisition of how the variables interact in addressing the objectives to understand the relationships evaluated.

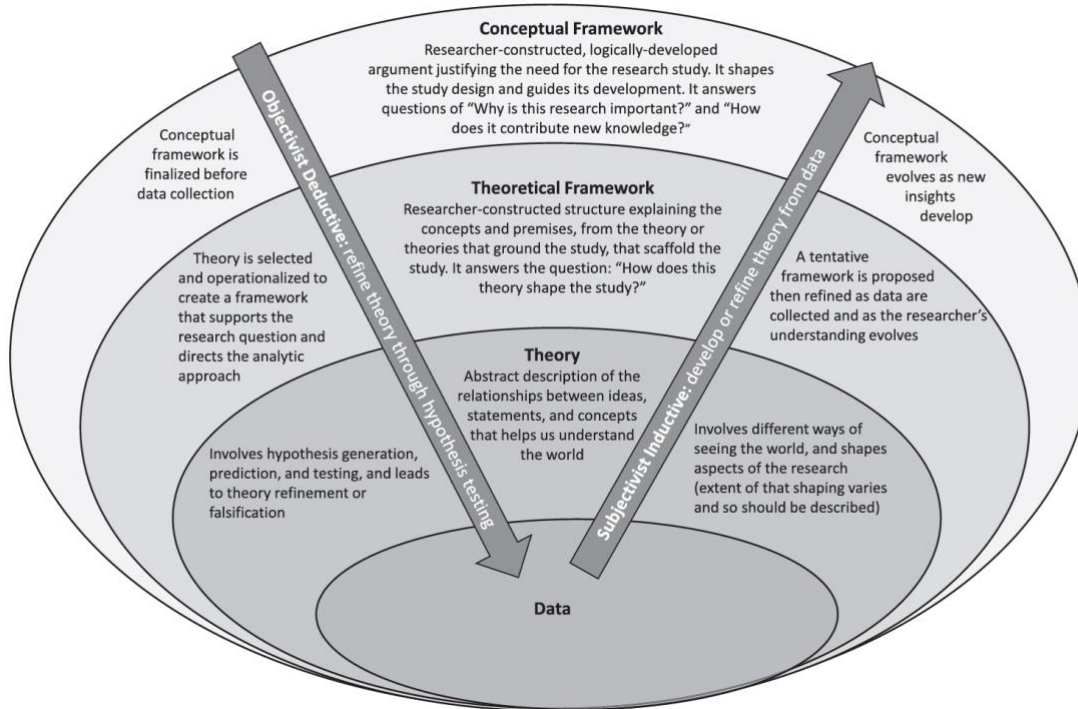


Figure 3. 1: Theory, theoretical framework and conceptual framework - adapted from (Varpio *et al.*, 2020).

The conceptual framework for this study is developed and underpinned by the three critical theories mentioned in Section 9, which are fundamental to the assessment and analysis of the adoption and utilisation of digitalisation or innovative technologies, and the relationship this has on the levels of observed construction productivity. It may be argued that digitalisation of construction operations and processes from inception phase through to construction phase, leads to both efficient and productive output (Ikuabe *et al.*, 2020; Berlak *et al.*, 2021), however this is not found to be the case across analysed literature. The method of analysis can be attributed to the extent to which digitalisation is researched, however the assertion cannot be validated or refuted without empirical evidence.

However, an in-depth analysis of the literature poses a counter- argument, that even though a positive perception may be the consensus, based on a design perspective, this positive outcome does not always manifest consistently across the project. This is due to variations between the levels of expected construction output and the observed construction productivity (Schober *et al.*, 2016; Osunsanmi *et al.*, 2018). Additionally, at a construction organisational level, the adoption and implementation of digitalisation or innovative technologies can theoretically be envisaged, and their output measured with perceptive accuracy. However, chaos theory argues that a construction process is dynamic in nature (Singh and Singh, 2002), and it is this

dynamism of the project that either inhibits or advances the perceived productivity, or even, subsequently, the measured outcome of productivity of a project.

Fernandez-Solis (2013) acknowledged that where chaos theory exists, productivity is assessed against a dynamic construction process. Furthermore, disruptive innovation theory also overarches the operation of the entire construction project. Moreover, the scheduled activities and the sequencing of construction work, follows the same dynamism. Notwithstanding this, the sequence of order remains susceptible to both intrinsic and extrinsic influences associated with the specified design and development methodologies, from the initial design phase through to the construction phase. (Ayers, 1997; Love *et al.*, 2002; Singh and Singh, 2002; Antunes and Gonzalez, 2015).

Table 3. 2: Coding of Soft Technologies and Hard Technologies.

Code (ST/HT)	Name of (ST/HT)
ST1	BIM Software
ST2	Predictive Analytics
ST3	Big Data Towers (BDT)
ST4	Digital Twin Towers (DTT)
ST5	Internet of Things (IoT)
ST6	Augmented Reality (AR)
ST7	Information and Communication Technology (ICT)
ST8	Cloud Computing
HT1	Robotics (production robots)
HT2	3D Printing Machines
HT3	Scan Surveying Machines
HT4	Scanning Drones
HT5	Virtual Reality (VR) labs
HT6	Modular Construction.
HT7	Digital Twins Towers.
HT8	Mobile Devices

This argument is derived from a synthesis of the identified theoretical frameworks, as well as empirical studies conducted over the past two decades. Collectively, these works posit that a knowledgeable and skilled construction system network encompassing design, production, procurement, and stakeholder engagement, thus contributes significantly to enhanced productivity in construction projects. However, a counterargument to this assertion is that a construction development does not operate in a vacuum, thus introducing the practicality of external and internal (environmental, technical, social, and managerial) factors which give rise to a variance of construction productivity observed, subsequently impacting the project success. A review of the literature indicates, as illustrated in Figure 3.2, that the study seeks to examine the relationship between the fundamental components that collectively constitute an understanding of soft and hard technologies, as well as the manner in which these components interact to form a unified digital platform. A direct feedback loop exists between ST and HT (Figure 3.2) as the one informs the other with regards to directives, halting methods, programming code and operational perspective (Maskuriy *et al.*, 2019). It thus becomes imperative to understand the dynamism and minimal (or radical) changes that exists between the two for the hypothesis to still retain its autonomy and validity for this study. As can be seen in Figure 3.2, Soft technologies have been coded ST1 – ST8 for the purpose of the study. The code names of what the various technologies, are referred to in Table 3.2. Similarly to Soft technologies, Hard technologies have also been coded HT1 – HT8 in the same custom. These technologies are coded for the purposes of understanding how when utilised and implemented on a construction project, do they impact the level of project productivity. Additionally, they are coded in this way so as to better analyse and evaluate the results of the study.

It further stands to be noted that these technologies have been cited and critically assessed by various scholars across different industries such as finance, manufacturing as well as automotive industries (Gray and Rumpe, 2015; Berger, 2016; Sveikauskas *et al.*, 2016). The construction industries – largely the procurement, design phase and development stage, has been plagued by the disenfranchised endemic of fragmentation, which still stands to date (Jang *et al.*, 2011; Hughes and Thorpe, 2014; Naoum, 2016; Barbosa, Woetzel and Mischke, 2017). If further follows that for the purpose of the study, an acute focus is positioned on the construction industry as it has seen an enormous uptake of adopting digital technologies (IDC, 2020).

The study acknowledges that some of the digital technologies (ST/HT) which have already been adopted and implemented, have evidenced a marginal shift with regard to the project productivities/performance (Berger, 2016; Barbosa, Woetzel and Mischke, 2017; IDC, 2020). Moreover, it has become imperative for those technologies that have already been implemented and adopted in the construction industry to be assessed for their efficacy as well as impact on the levels of construction project productivity/project success as an avenue to determine their broad use and implementation on a larger scale projects (Maskuriy *et al.*, 2019; Chen *et al.*, 2022). Moreover, it is essential to comprehend that at the backdrop of these technologies and advanced methods to go the digital avenue in the construction industry, there are elements that have a major inhibiting proponent to the ease of adoption. Additionally, elements that possesses an enabling association which could increase and impact the productivity of projects in a varying observation to the endemic perception of construction projects always expressing time and cost overruns (Barbosa, Woetzel and Mischke, 2017). Furthermore, from an optic of project inception of the through to the completion of a project.

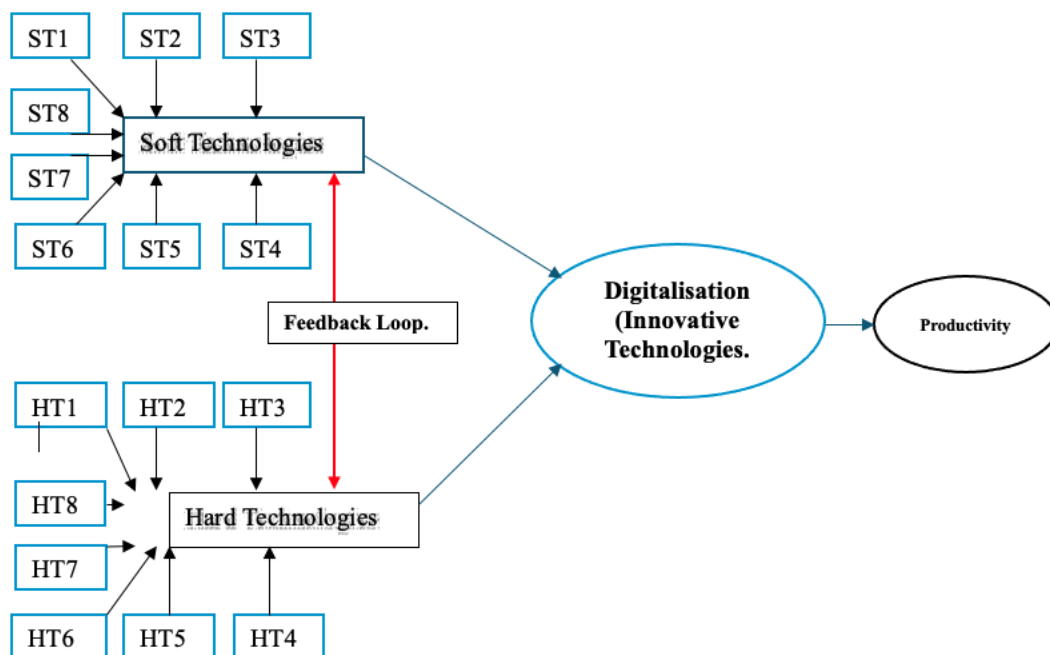


Figure 3. 2: Relationship between Technologies (soft and hard), the adoption impact on Project Productivity.

Additionally, it is critical to understand the relationship that digital technologies have, as well as the elements comprised within these technologies and how they impact the efficacy of a

construction and development in the long run. Moreover, an inquiry into if these technologies are adopted and implemented on a project, what potential precepts will dictate their ease of implementation and adoption. Thus, this relationship is represented by Figure 3.3 in expressing the barriers (B1 – B7) as being probable deterrents to the implementation and adoption of the digital technologies in the construction industry. It should further be acknowledged that barriers (E1 – E7) to the adoption of digital technologies can be explained by a range of factors, which also offer pathways to facilitating easier and more systematic adoption of these technologies.

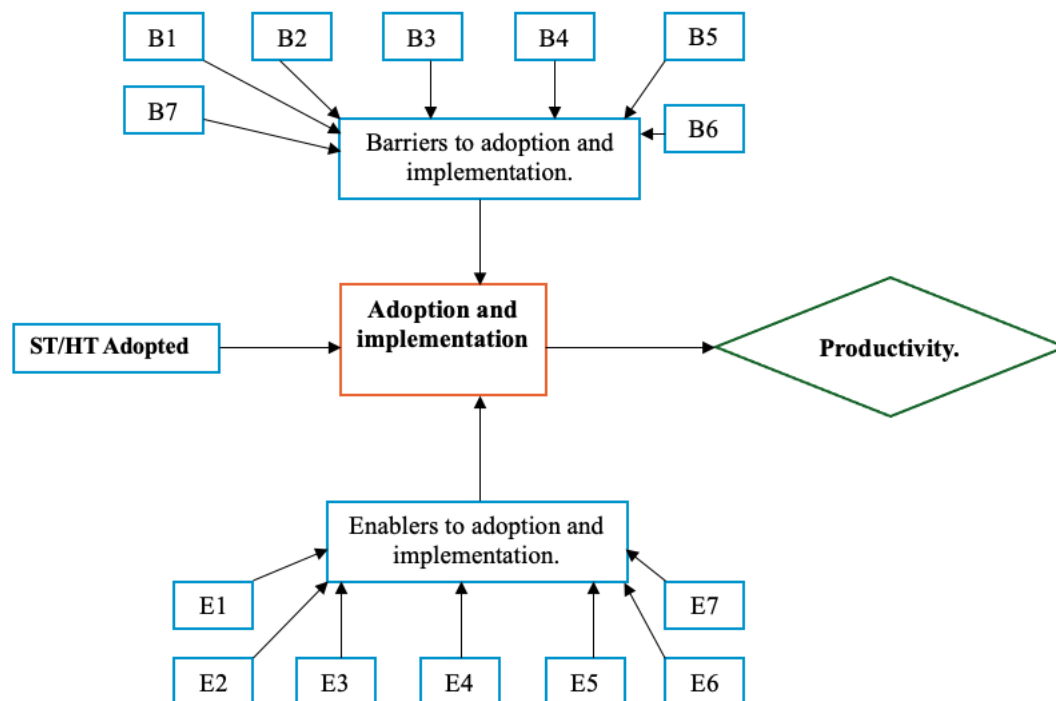


Figure 3. 3: Relationship between DTs and Project productivity

Figure 3.3 evidence a combination of the barriers as well as the enablers that act upon the productivity of the selected or utilised mode of digital technology. Enablers and barriers, when operationalised within a construction project context, may exert differential effects on the attainment of projected output levels, thereby influencing overall project productivity. Moreover, depending on kind and type of digital technology adopted and implemented on a construction project, the resultant effect on the output (productivity) of the project can be

quantified. For the purpose of this study, the level of productivity, is the determined constructs reported in Table 5,15. Furthermore, Figure 3.3 illustrates that the level of output can be evaluated in terms of the extent to which it is influenced by operator or worker proficiency, technological competence, and an understanding of operational requirements, as well as the effective utilisation of the technology. And the level of output can be measured by multiple techniques such as cost, time and quality of the finished project. Additionally, Figure 3.3 is not definitive with regards to the kind of output that is evidenced on the project.

Following this, a refined and clear hypothesis becomes critical to the assessment of whether these digital technologies implemented yield the required levels of productivity (Victora *et al.*, 1997; Creswell, 2009; Karpov, 2010; Shikalepo, 2020; Varpio *et al.*, 2020). Given the interconnected and sequential nature of digital technologies and their direct influence on construction project productivity, the hypothesis formulated in this study is grounded in a critical interrogation of the literature and a synthesis of pertinent theoretical frameworks, as presented in Figure 3.4. The developed hypotheses for this study are.

H1: There is a significant relationship between digitalisation techniques (innovative technology) and the level of construction productivity on projects.

H2: There is a significant relationship between external factors and adoption-willingness for construction organisations to implement digital technologies.

H3: The relationship between skills (knowledge of digitalisation technology/innovative technology) and construction project productivity is moderated by training and adoption of digitalisation technologies (innovative technologies) on projects.

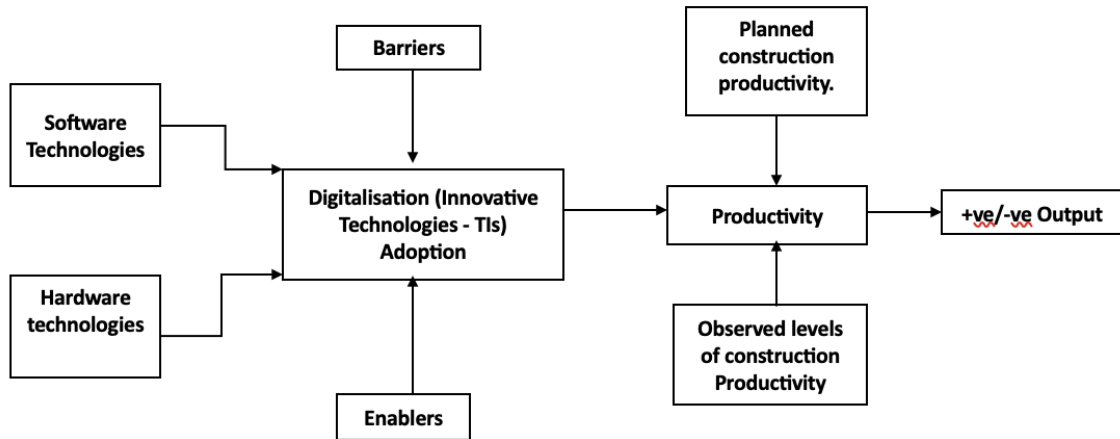


Figure 3. 4: The relationship between the implementation and adoption of digitalisation technologies and project productivity.

3.5 Chapter Summary

This chapter outlines the definition of theory and interrogates theories pertinent to supporting the research ideology. Furthermore, a synthesis of these theories is interrogated against the already existing theories in literature. However, only those theories which acutely aligns with modelling digital technologies and the resultant impact on levels of project performance, are adopted for the study and a synopsis of which is discussed. These theories are Disruptive Innovation Theory (DIT), Configuration Theory, Chaos Theory and Technology Adoption Model (TAM) Theory. These theories support the proposed hypothesis that a relationship exists between the adoption of digital technologies, and they further purport that an evidenced improvement on project output is observed. However, in the analysis of these theories, the chapter also expresses that the degree of effect can be evaluated through testing the hypothesis. This chapter also outlines a sequential formulation of the conceptual study. The developed conceptual framework is expressed in tiers so as to clearly indicate the various variables which play factor in the assessment of the project output. The first tier is the analysis and inquiry into the various forms of technologies construction projects are familiar with in the South African construction industry (ST and HT). The second tier is the elemental combinations which acts on the efficacy and practicality of adoption of these technologies. These are barriers (B1 – B7)

and enablers (E1 – E7). The last tier of the conceptual framework is the amalgamation of digital technologies, barriers and enablers to assess the subsequent impact these have on the project productivity output. Lastly the study expresses how the formulation of the hypothesis is done and moreover, the linkage this has on the methods and analysis techniques to be carried out in answering the research question.

CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 Introduction

This section presents the research methods, philosophies, approaches, strategies and techniques engaged in the analysis and presentation of the collected data for this study. This is primarily for the purpose of addressing the research objectives, testing the hypotheses, and answering the research question. A rigorous and well-constructed research methodology is a crucial substratum upon which one can comprehend, detail and succinctly clarify the strategy adopted in the exploration of objectives and subsequently, answer the research question. Research methodology establishes the sequence through which the research question is addressed, enabling the systematic identification of the core elements of the research problem and providing a coherent framework for its resolution. Additionally, the conceptualisation of the research methodology is developed from analysing the literature intrinsic to the research. Moreover, this is also generated from previous studies conducted in the same field of science as an attempt for the findings to be generalisable.

4.2 Research paradigm

Research methodologies cannot be reduced to the research techniques applied; it is also imperative to fully understand the form of data envisaged for the study (Kothari, 2004; Saunders, 2009). This is to necessitate and foster a holistic perception of the research methodology. Furthermore, the appropriate selection of data analysis techniques is necessary for the research (Saunders *et al.*, 2003; Saunders *et al.*, 2015). It is for this reason that the positionality of this study is cemented in a logical, grounded philosophy, approach, and analytic tools to promote clarity and understanding of the research.

The research question is formulated in a manner that does not restrict or confine the study to a single research paradigm, thereby allowing for methodological flexibility across paradigmatic approaches. As a result, the study will adopt a mixed method research paradigm. Over the past decades, research in both the social sciences and behavioural sciences, engineering and medical fields has adopted a mixed-methods research paradigm in the interrogation and understanding of constructs (Johnson and Onwuegbuzie, 2004). Compared with both quantitative and qualitative research paradigms, each of which independently constitutes a robust, well-articulated, and widely recognised approach to research, the mixed-methods paradigm is

preferred. This preference across scholars is attributed to its propensity to interrogate and provide the most pragmatic method of interpretation (Johnson and Onwuegbuzie, 2004; Kivunja, 2018).

The built environment constitutes both a technical and socio-economic industry. Its technical structure is shaped by the interrelationship between operational technologies (including tools and equipment) and the human element involved in their application and management. The adoption and implementation of digital technologies, centres at the nexus of culminating these two constructs. Underpinning this is the understanding of the labour component's engagement with digital technologies in project development endeavour (Abowitz and Toole, 2010). It is this inquiry that this study adopts the positivist research paradigm. Saunders *et al.* (2003) provides an elaborate and intrinsic research map, commonly referred to as the research onion as presented in Figure 4.1. This roadmap presents a systematic overview of the various research philosophies and approaches, which collectively provide a clear rationale for the selection of the positivist paradigm for this study. In addition to the research onion providing insight in the development of research framework, Saunders (2009) further explicate that in its nature of being a research guide; the positivist research approach can also be conflated to mean a scientific method which allows for the aggregation of data and commands an expansive statistical tools and methods to deduce meaning from data collected (Creswell, 2009; Saunders, 2009; Kivunja, 2018).

The primary justification for adopting a positivist research paradigm lies in its inherently logical and deductive orientation (Mackenzie and Knipe, 2006; Creswell, 2009; Kivunja and Kuyini, 2017; Kivunja, 2018). The approach acts as a catalyst in the formulation and strategic selection of the statistical packages necessary to test the research hypothesis. It is this benefit which provides meaning to the analysed findings. Moreover, making it easy to explain the findings. Fundamentally, on the prospect of assessing the generalisability of the results or refuting the test (Fadhel, 2002; Mackenzie and Knipe, 2006; Kivunja, 2018). The adoption of positivist research approach for this study cannot be assessed in isolation to the inter alia studies in which it was adopted.

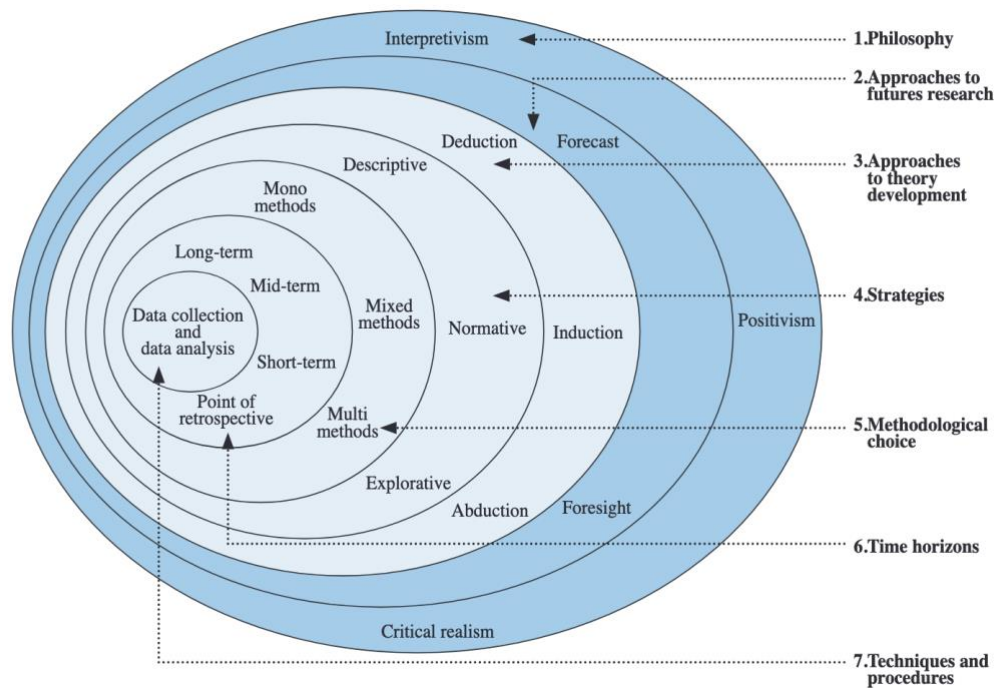


Figure 4. 1: Research Onion (Adapted from Saunders (2009)).

A global study conducted by prominent consultancy firms embarked on research to distil and capture the variations in factors impacting the implications and effects of the adoption of digital technologies. Barbosa, Woetzel, Mischke, *et al.* (2017) employed a positivist research approach and produced findings that partially addressed the barriers and challenges that various countries encounter in adopting and implementing digital technologies in construction projects. Notwithstanding that, in their adoption of the positivist approach, a myriad of factors was omitted, particularly those which are endemic to developing countries such as South Africa, and those which are project specific.

This research paradigm was adopted by IDC (2020) in which the objective was to assess the readiness and the predisposition of adoption by construction organisations and development. This study also followed a positivist research approach in elucidating the research findings which served as constructs analysis for the development of the adoption conceptual framework. This further anchors the legitimacy and interrogative nature of the positivist research approach (Creswell, 1996; Johnson and Onwuegbuzie, 2004; Mackenzie and Knipe, 2006; Creswell, 2009; Creswell and Clark, 2017b; Kivunja, 2018). In drawing from scholars who have conducted research in digital technologies (the adoption and implementation), particularly the

utilisation of the positivist research paradigm; the positioning of this research in that domain commands an avenue of centralisation amidst such studies. The causation and effect of digital technologies on the project productivity is the focal aim of the study. In asserting this study's position and its substantiation for the utilisation of the positivist research paradigm, scholars have evidenced through research the merits of the positivist research approach (Durdyev and Mbachu, 2011; Farnad and Pouya, 2013). This was largely due to the implication of their research which was the exploration of causation and effect in the factors giving rise to the variations in the project productivity. Their scholarly inquisition was additionally supplemented by Naoum (2016), Niazi and Painting (2017), Osman and Ahmed (2017) and Gephart (2004) in following the positivist research approach in the answering and addressing of the research objectives of the study. Furthermore, the similarity between their findings aligns with the conclusions of the present study in relation to the testing of the research hypothesis.

Deductive lens in the understanding and the analysis of data ought to not be misconstrued with that of the inductive approach as the two are complements of each other in the analysis of quantitative component of data (Creswell, 1996; Corley *et al.*, 2021). Varpio *et al.* (2020) laments this ideology in postulating that the inductive research approach uses a specific construct as a point of departure in the conceptualisation of an occurrence. Furthermore, this construct aid in the building up or the explanation of the findings from an elaborate and holistic approach (Creswell, 2009; Varpio *et al.*, 2020). Notwithstanding that, it stands to be noted that inductive research approach advances the significance of a research's findings. Moreover, this is poignant cornerstone in deducing meaning and understanding from research which otherwise, the interpretivist approach can miss (Corley *et al.*, 2021). This sentiment is posited this way in that the interpretivist research approach primarily uses scientific statistical or mathematical inference to draw meaning from the data.

However, deductive approach harnesses the subjectivity and otherwise areas which are not explore in detail or missed through the omission of the qualitative assessment (Creswell, 2009; Kivunja, 2018; Corley *et al.*, 2021). It is further observed that a range of digital technologies are employed within the construction industry, both internationally and within South Africa's national construction sector. Additionally, the skills and requirements for the utilisation of these digital tools vary from project to project, particularly when classified in the project types (Barbosa, Woetzel and Mischke, 2017; IDC, 2020). The uptake and inclination in utilising digital technologies on construction projects can be affected by a myriad of factors. It is the

utilisation of deductive research paradigm that various experiences of the professionals using these tools, can easily be understood. Moreover, these experiences and data should be synthesised in accordance with the principles of the deductive research paradigm to enhance the understanding of diverse experiences and their influence on project productivity. (Creswell, 1996; Saunders, 2009; Varpio *et al.*, 2020; Corley *et al.*, 2021).

4.3 Research approach

A research approach is imperative in conducting any research as it sets precedence of the nature and provides robustness to the research findings envisaged for the study (Kumar, 2014). A plethora of research approaches are found in literature. However, certain fields of the research domain do not have specific approaches which are specific to that science. The social sciences encompass a range of methodological approaches that may be applied across various fields of inquiry. However, each approach possesses specific strengths and limitations and this may yield inappropriate or misleading outcomes when applied to research questions for which it is not suitably designed (Golafshani, 2003; Saunders, 2009; Varpio *et al.*, 2020). It stands to be noted that this research covers a complex and relatively new concept in the development of the construction industry. In lieu of that, the construction industry as a whole is prominently known as being a fragmented industry with professionals and experts in the field operating in silos (Baloyi and Bekker, 2011; Soekiman *et al.*, 2011). In addition to that, another this research presents; is that of the impact of the external (technical, environmental, managerial and social) factors to the adoption and implementation of digital technologies which are seldom overlooked. However, have the propensity to impact the construction of a project and project productivity significantly (Kadir *et al.*, 2005; Soekiman *et al.*, 2011). Much of this assessment or the analyses can be conducted through the testing of a hypothesis, conducting statistical tests or quantifying the impact based of a hypothesised unit of measure (quantitative approach). However, an expansive perception of the externalities and feasibility of the study can also be dredged from experiential and individualistic perception of the research respondents (qualitative approach). It is for this rationale that the study adapts the mixed methods research approach. The selection of this approach is based on the capacity of qualitative and quantitative methods to complement one another by mitigating their respective limitations and enhancing the overall robustness of data analysis (Johnson and Onwuegbuzie, 2004; Creswell, 2009; Saunders, 2009; Migiro and Magangi, 2011).

4.3.1 Quantitative research approach

This study adopted a quantitative research approach as one of the research approaches. In establishing the rudiments of the approach and how it acutely aligns with the research objectives, it is imperative that there is an understanding of the meaning and fundamental principles of the research approach. Across scholars that have engaged and distilled the true meaning of quantitative research approach, it is synthesised that quantitative research approach can be defined as a research strategy that places significant emphasis on the quantification and aggregation of the constructs measured. This definition is expanded further in that this statistical phenomenon can be presented empirically through components referred to as variables the results of which can be presented numerically as frequencies, rates or averages. Moreover, a relationship can be established through these variables with the utilisation of statistical techniques to systematically deduce meaning (Johnson and Onwuegbuzie, 2004; Creswell, 2009; Saunders, 2009; Migiro and Magangi, 2011; Rasinger, 2013; Rahman, 2016; Creswell and Clark, 2017b). For the purpose of this study, this definition is to be adopted throughout the utilisation of the qualitative research approach. The selection of quantitative research approach must be substantiated, especially for the objectives set out for this study.

A fundamental key aspect of the quantitative research approach is the capability to have the findings of the research generalisable (Rahman, 2016). Generalisability of the findings is eminent purely due to the size of the sample size used, and the findings (analysed data) can easily be applied to a population or sub-population from which the research is conducted (Carr, 1994; Creswell, 2009; Rahman, 2016). The application of statistical software, such as SPSS, enhances the efficiency of data analysis by reducing the time required to perform analytical procedures (Johnson and Onwuegbuzie, 2004; Rahman, 2016). Similarly, when a quantitative research approach is employed, the distribution of research instruments can be carried out relatively efficiently and within a shorter timeframe. (Johnson and Onwuegbuzie, 2004). A fundamental vantage point this research approach provides is neutrality between the researcher and respondents. This, therefore, eliminates any form of influence or interference affecting respondents, thereby ensuring that unbiased results are obtained (Johnson and Onwuegbuzie, 2004). Furthermore, the utilisation of quantitative approach is revered to provide precise, statistical and numeric data which is generally perceived to have more credibility and rigour (Johnson and Onwuegbuzie, 2004; Creswell, 2009; Saunders, 2009). Lastly, the rationale in adopting this approach for this study is that a large number of respondents can form part of the

study and responses aggregated and analysed to synthesise meaning to the data (Creswell, 2009; Rahman, 2016; Mulisa, 2022).

4.3.2 Qualitative research approach

A notable point of contention that exists through literature, especially when using qualitative research approach, is the approach's ability to possess minimal limitations in its extend of analysis (Creswell, 1996; Golafshani, 2003; Mulisa, 2022). The definition of qualitative research design has long been a point of contention among scholars. This is largely attributed to the implication and assertion made by Wang *et al.* (2020) in that there is no one single absolute definition. However, commonalities of what can be adapted as a working definition for qualitative approach is synthesised through scholarly research, particularly those whose field of science is research methodologies and approaches of this nature. These scholars define qualitative research approach as one which permits the researcher to scrutinise the participants lived experiences across core precepts of the research constructs. Furthermore, this examination of participants can be expressed in holistic and all-inclusive detail with the utilisation of specific research approaches and philosophies. These philosophical perspectives and methodological approaches are not limited to in-depth interviews, focus group discussions, observations, and participants' experiences of the constructs under investigation; they also facilitate the collection and analysis of large datasets, thereby enabling a more comprehensive understanding of the research phenomenon (Saunders *et al.*, 2003; Johnson and Onwuegbuzie, 2004; Creswell, 2009; Saunders, 2009; Migiroy and Magangi, 2011; Wang *et al.*, 2020). This research follows and adopts this definition of qualitative approach. It further stands that since this definition elucidate the context of qualitative approach; it then follows that the fundamental aspects which will instil the use of this approach for the study be explored in-depth.

It follows then that the merits of why qualitative research approach is utilised for this study, begs an interrogation of how the method benefits the study, particularly in answering the research question. One of the key strengths of qualitative research approach is that it generates data grounded in participants' own interpretations and meanings, allowing respondents to articulate their perspectives and experiences in response to the questions posed (Johnson and Onwuegbuzie, 2004). It is this elaborate expansion of responses that affords the study rigour of supplementing the quantitative component of the research with in-depth analysis. Johnson and Onwuegbuzie (2004) purports that in the nature of how expansive and holistic qualitative

approach is, this is an advantage to the researcher as it allows the participants to land themselves in the space of thought where they further expand upon their responses as they interrogate the *why* and *how* a particular phenomenon occurs. In this study, this will be *why* do digital technologies need to be implemented and adopted in the construction industry and *how* does the inclusion of digital technologies affect construction project productivity. Another fundamental quality of qualitative method is the ability to provide a simplistic explanation in the breaking down of complex phenomena into understandable manner (Johnson and Onwuegbuzie, 2004; Creswell, 2009; Migiro and Magangi, 2011).

It is for this rationale that the explanation of the various technologies, as complex of a concept they are in the development of a construction project, are synthesised easily through participants so that a common explanation of this complex construct is easily understood. Moreover, this is to ensure the respondents provide information devoid of any misinformation which may jeopardise the quality of data. A key strength of qualitative research is its ability to provide a comprehensive understanding of the phenomenon under investigation by generating rich, context-specific insights that are grounded in the experiences and perspectives of participants (Johnson and Onwuegbuzie, 2004; Maxwell, 2010; Creswell and Clark, 2017b). This insight is supported by the geographical extend of reach this study envisage. Furthermore, the variances in cidb grading of companies/participants, provinces they reside, project type and specialisation of the job, enriches this perspective. This element of qualitative research method allows a thorough and elaborate assessment of data. This championed by the techniques utilised in gathering data for generalisability and validity (Saunders, 2009; Kivunja, 2018). Accordingly, a qualitative research methodology serves as the central methodological framework guiding this study, as it provides the most appropriate means of addressing the research objectives (Abowitz and Toole, 2010).

4.3.3 Mixed-method research approach

The definition of mixed method takes on various interpretations; this is especially pertinent considering the multitude of methodological combinations that may be employed within the industry. For the purposes of this study, the adopted definition of mixed methods is as follows: mixed methods research refers to a research approach in which a researcher integrates both quantitative and qualitative research techniques, as well as their respective analytical methods and conceptual frameworks, within a single study (Johnson and Onwuegbuzie, 2004; Maxwell,

2010; Migiro and Magangi, 2011; Subedi, 2016; Creswell and Clark, 2017a).

Johnson and Onwuegbuzie (2004) further postulated that a mixed method research approach offers a logical and practical perspectives to the data collected and the mode in which it is analysed. This stems from the fact that a quantitative aspect of research offers the pragmatic component to data as further elaborated by Curry (2012). Furthermore, there is also a component of dynamism offered by quantitative data. In summation, the mixed method approach is lauded as one of the superior research approaches as it allows quantitative and qualitative approaches to complement one another and foster a complete scope to the research analyses. Notwithstanding that, mixed method approach gives legitimacy to the research question in removing constraints or containing the researcher to one monolithic method of assessment (Migiro and Magangi, 2011). This research approach allows for an expansive interrogation of the research question, approached from different methods, particularly when utilising the strengths of those methods combined to form a singular approach to the study (Creswell, 1996; Johnson and Onwuegbuzie, 2004). This further implies that the credibility and validity of the research findings are enriched as this allows for ease of identification to areas of convergence and divergence in research results (Holt *et al.*, 1995; Creswell, 2009; Rahman, 2016; Kivunja, 2018; Corley *et al.*, 2021). This adoption preambles the nature of the research question and the extent of adoption and implementation of digital technologies in the South African construction industry. As most construction companies are recently acclimatising to digital adoption and implementation (IDC, 2020; Kavuri *et al.*, 2020), this approach allows extraction of significant quantity of data, information and allow the utilisation of various quantitative and qualitative tools and techniques to analyse data.

4.4 Research strategy

As much as the research approach is pertinent to research, strategy equivocally plays a pivotal role in elucidating and creating a robust study. It is argued that throughout the 20th century, behavioural and social scientists frequently employed a mixed-method approach as a framework to anchor research (Tashakkori and Teddlie, 2003; Creswell, 2011; Subedi, 2016). This has been an observed phenomena in the 21st century even though strides have been made since in understanding and expansion of research strategies (Tashakkori and Teddlie, 2003).

Subedi (2016) posits that there are six various kinds (strategies) of mixed method designs in both literature and studies that have already been conducted. These various kinds of mixed method strategies are labelled as: convergent parallel design, explanatory sequential design, exploratory, embedded design, transformative design and multiphase (Tashakkori and Teddlie, 2003; Creswell, 2011; Subedi, 2016). A key point of contention in the application of any of the six mixed-methods designs lies in the researcher's intellectual task of formulating a research question with complete clarity and without ambiguity (Subedi, 2016). It is through this assertion that a researcher can acutely synthesise the research question in a modus that allows ease of understanding. As expressed, literature alludes to various mixed-method designs that fall within the mixed-methods approach categorisation; it is thus imperative that the design selected and to be adopted for this study be expanded further. This study adopts the convergent parallel mixed-method design, as presented in Figure 4.2.

A key strength of employing a convergent parallel mixed-methods design is that quantitative and qualitative data are collected concurrently, allowing for the integration of both forms of evidence within the same phase of the research process (Creswell, 2011). Furthermore, both datasets (qualitative and quantitative) are analysed separately with the tools and techniques relevant to their analysis. Additionally, the results of both the qualitative and quantitative datasets are interpreted as purported by Figure 4.1. The interpretation of both datasets is primarily focused on the extent of congruence between the statistical findings derived from the quantitative component and the insights generated through the qualitative component of the dataset. Additionally, this further assess if contradictory findings exist in the absence of congruence (Teddlie and Yu, 2007b; Creswell, 2011; Heyvaert *et al.*, 2013; Subedi, 2016). This direct comparison, as postulated by Subedi (2016); is what gives the findings of the study the convergence quality.

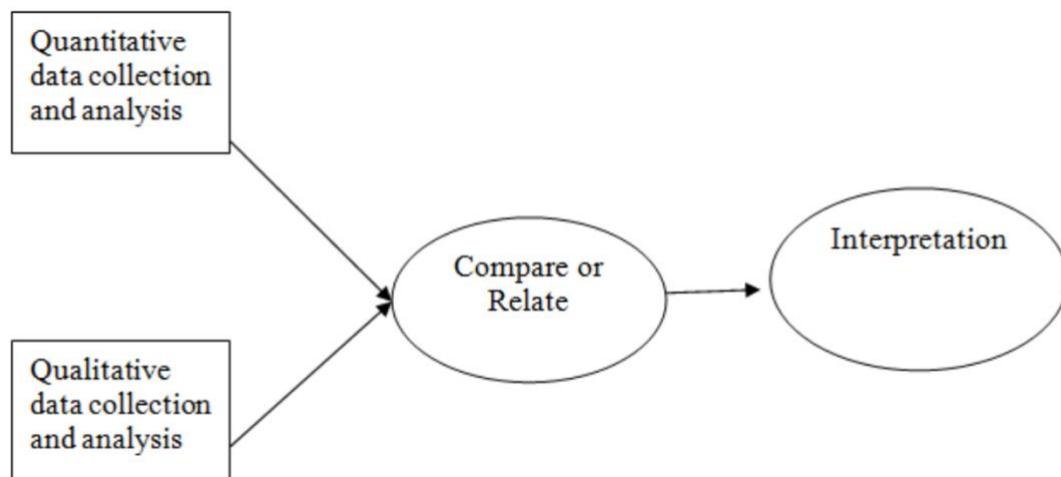


Figure 4. 2: Convergent Parallel Design – Mixed Methodology Adapted from (Creswell, 2011; Subedi, 2016).

Literature further expands the rationale of why the convergent parallel mixed design has garnered popularity across scientific and human behavioural sciences (Rahman, 2016; Subedi, 2016; Creswell and Clark, 2017b). One of the fundamental benefits is that the results of this mixed-method design provide a holistic and elaborate perspective of the findings which gives credibility and rigidity of the research question. Additionally, the utilisation of convergent mixed-design strategy provides more analysis to findings. This interpretation is primarily derived from a qualitative perspective, as the analysis extends beyond numerical (scientific) measures and instead emphasizes experiential and practical responses relevant to the research question (Heyvaert *et al.*, 2013; Creswell and Clark, 2017a). Lastly, a robust and validated perspective of research results can be achieved through strengths of both quantitative and qualitative spheres of convergent mixed-method design. It can therefore be concluded that this mixed-methods approach is well aligned with the research question and its subsidiary questions and is appropriate for addressing the objectives of the study.

4.5 Population, sampling technique and sample size.

4.5.1 Study Population

Study population is considered an important aspect of the research study as it is the bedrock from which the research question can be answered and the findings of which generalized, depending on the type of population used. The study population refers to the complete set of individuals or subjects sharing defined characteristics from which a sample may be selected (Creswell, 2009; Smith and Noble, 2014; Thacker, 2020). However, Thacker (2020) draws a

notable parallel between the two types of populations that exists in social sciences and how they affect the study. The first kind of population is referred to as the target population which is a type of population that consists of all the elements and variables which are pertinent and specific to the study and its objectives. In the context of the construction industry and for the purposes of this study, the target population comprises all construction firms classified within cidb Grades 4 to 9. A further distinction is made between this target population and the accessible population, which refers to the subset of the target population that is practically available for inclusion in the study. This population primarily refers to the individuals that can be procured with ease for the purpose of research or any study. However, accessible population is devoid of rigor and impartiality that is required for a study, particularly when evaluated from the mitigative means of eliminating bias (Smith and Noble, 2014; Thacker, 2020). The rigor and depth with which a research question is addressed depend on the characteristics of either of the two specified population types. Target population comprises of a vast number of subjects potentially suitable for the study with various levels of competencies and spread across the nine (9) provinces in South Africa. This further reinforces the probability of the findings to be better positioned for generalisability across the construction industry. Conversely, accessible population is restrictive and imposes a limitation to the expansiveness of the research. This can be evidenced in that when population is only accessed from one (1) province in South Africa, depending on the multitude of variables that affect that province such as riots, environmental, material, labour and economic status, this population yields the results which cannot be generalised (Smith and Noble, 2014; Thacker, 2020; Noor *et al.*, 2022). As a result, this study adopts the approach target population envisage for a generalisable outcome.

The study aims to interrogate digital technologies employed in the construction industry and their resultant impact on project productivity. This inquisition demands expert knowledge of the procurement of construction resources, management of both labour and organisational structure as well as the financial implications of utilising or implementing new digital tools to advance the development of a project. Notwithstanding this, the level of inquiry takes into account a range of experiences and exposure to various digital tools. Consequently, an individual's designated position within an organisational organogram is used as one of the metrics for selecting the target population for this study. These are individuals whose input is anchored by experience and complexity of responsibilities (directors, contract managers, project managers, site agents, construction managers, site engineers, construction supervisors,

quantity surveyors, estimators, cost engineers).

According to cidb (2022), the requirements for registration on the cidb registry are well defined. The categorisations are classified according to the apportioned range of value (in rands) that each contractor intending to register can undertake as tabled in Table 4.1. This categorisation also applies to contractors intending to move up a grade. Notwithstanding this, the present study focuses on the categorisation spanning Grades 4 to 9. The rationale behind the selection of this category of contractors is based on the maximum project value which contractors can tender for. These grades possess financial resources that enable them to experiment with digitalisation, particularly through the adoption of these digital tools implemented as software packages. Furthermore, those in Grade 8 – Grade 9, can expand the scope of their integration of digital technologies that supersedes only software packages, but also wearables, VR equipment and drones in their operations. Another axis the study intends to attain sufficient data from the targeted population, is to assess the cidb registry of contractors according to the specialisations of the work carried out.

Table 4. 1: Contractor grading categories, financial turnover and available capital.

CIDB Grade	Estimated Contract Value (in rands)	Track record/ largest contract completed during 5 years before application, in the class of construction work applied for.
Grade 1	500 000,00	-
Grade 2	1 000 000,00	130 000,00
Grade 3	3 000 000,00	450 000,00
Grade 4	6 000 000,00	900 000,00
Grade 5	10 000 000,00	1 500 000,00
Grade 6	20 000 000,00	3 000 000,00
Grade 7	60 000 000,00	9 000 000,00
Grade 8	200 000 000,00	30 000 000,00
Grade 9	No Limit	90 000 000,00

According to (cidb, 2022), the categorisation of contractors is split according to the main contractor categories as well as the specialised classes of work. This study focuses on the main contractor's categories which are civil engineering (CE), General Building (GB), electrical engineering building (EB), electrical engineering civil (EP) as well as mechanical engineering

(ME). These categories are selected due to the complexity and the intricate work carried out. Furthermore, the development of a project integrates all relevant specialisations from the design phase and requires that all members of the professional team coordinate their outputs such that their drawings can be overlaid, ensuring the production of a single coherent master drawing (Zhang *et al.*, 2020). As a result, the concentration of these specialities as the target population affords the study a vast data set. For this study, the study population was drawn from the database (repository) comprising of cidb ROC, which is updated yearly, directors across social platforms such as LinkedIn and referrals from industry partners and colleagues. From these lists, a total of 2810 participants were selected as the population for the study as they fell within the category Grade 4 – Grade 9.

4.5.2 Sampling techniques

The strength of any research depends on the researcher's ability to succinctly identify and establish the type and method of sampling used in the research. As a result, it is imperative to establish what the definition and meaning of sampling refers to in the context of research. Scholars postulate that the extrapolation of a segment of a targeted population to draw a generalisable conclusion can be referred to as a study sample (Teddlie and Yu, 2007b; Creswell, 2009; Taherdoost, 2016a; Thacker, 2020). In place of this definition, the study corroborates the assertion posited by Thacker (2020) in that the specificity of a target population enriches and validates the generalisability of the study, especially when the target population comprises of a subset the study intends to test. Furthermore, it is vital to note that the study only focuses on construction professionals that are active in the construction industry within South African. Furthermore, Taherdoost (2016a) The statement draws a clear parallel in challenging the assumption that sampling techniques used in social science research are uniform or monolithic across studies.

Two distinct sub-categories of sampling techniques predominantly used across social sciences are probability sampling (random sampling) or non-probability sampling (non-random sampling). Within these sub-categories, lies a broad range of sampling techniques that largely relies on the research question envisaged to be answered as well and the defined population type which is the primary sample space (Kaynak, 2003; Johnson and Onwuegbuzie, 2004; Creswell, 2009; Abowitz and Toole, 2010; Saunders *et al.*, 2015; Taherdoost, 2016a).

Notwithstanding that, these two clusters have a poignant distinction which allows the researcher to interrogate merits and demerits of each. Probability sampling refers to the chance that any member of the population has an equal chance of being selected to form part of the study (Teddle and Yu, 2007b; Abowitz and Toole, 2010; Taherdoost, 2016a). Within the context of this study, anyone that is registered on the cidb registry of contractors, has an equal chance of being selected for this study. However, the limitations and population of this study only focuses on all those members that fall within the category Grade 4 – Grade 9 on the cidb registry. Taherdoost (2016a) corroborates a sentiment posited by Brown (1947) in reporting that probability sampling significantly eliminates any bias in research thus fitting for conducting any study. Additionally, a counter effect of the technique is that with regards to time and effort expended, it can be expensive, depending on the selected technique within this sub-category. This is largely evidenced by the selection of a technique that may involve travel costs, administrative expenses, and the retrieval of data from sampled participants across the target population (Brown, 1947; Taherdoost, 2016a).

Juxtaposed to the probability sampling, is the non-probability sampling. This technique is mostly used when conducting a case study. The utilisation of a case study research approach consists of an arduous task of selecting cases or projects that are acutely congruent with research objectives. As a result, a case study approach focuses on samples which are not large in number (Creswell, 2009). Furthermore, the synthesis of which is to draw data from the participants which mirrors lived experiences or follows projects which are in the process of being built or completed (Hancock *et al.*, 2021). This is however instituted without an extensive use of statistical tools to analyse the data or draw conclusions (Teddle and Yu, 2007a; Taherdoost, 2016a; Hancock *et al.*, 2021; Noor *et al.*, 2022).

Probability sampling consists of several sub-categories of sampling methods commonly employed in the social sciences. These include simple random sampling, stratified sampling, and cluster sampling. In some classifications, convenience sampling is also referenced, along with multiple probability techniques, although it is more typically considered a non-probability sampling method (Teddle and Yu, 2007b; Creswell, 2009; Taherdoost, 2016a; Creswell and Clark, 2017b). Teddle and Yu (2007b) expand this in postulating that these sampling methods are overarched by the kind of sampling distribution observed when employing either of these methods. Normal distribution of the data being one of the widely observed phenomena.

Random sampling refers to a sampling procedure in which each individual within the target population has an equal probability of being selected for inclusion in a study. This can be implemented through various methods. For example, a researcher may assign a unique identifier, such as a number or code, to each member of the population and then randomly select from these identifiers to determine which individuals are included in the research sample. (Teddle and Yu, 2007b). Taherdoost (2016a) raises a critical concern that when the target population is not fully and clearly defined, this method is highly likely to produce outcomes that do not align with the objectives of the research. This means that the population under which data is sought, need to be distinctly identified. Therefore, this study utilises the cidb Register of Contractors as its data source. The study population comprises contractors classified within Grades 4 to 9 who are actively listed on the register.

Stratified sampling is a method in which a target population is divided into distinct sub-groups, or strata, based on a shared characteristic or unifying factor (Teddle and Yu, 2007a; Taherdoost, 2016a). This method is primarily employed when the researcher intends on giving a representative optic of the entire population. Furthermore, because this method yields a representative depiction of the population, even when divided into relevant subgroups, it incorporates an element of random sampling within each stratum. This enables more robust generalisations to be drawn from the observed data to the broader study population (Taherdoost, 2016a). In the context of this study, contractors across various cidb grades are targeted, with each member within the respective grades having an equal probability of selection. This approach is adopted to ensure that the research question is investigated impartially and that the findings are representative. Consequently, the results may be generalised to the broader construction industry, specifically to contractors registered with cidb who hold active status.

Cluster sampling is when the researcher deliberately chooses a group or a cluster which forms part of a population (Taherdoost, 2016a). Cluster sampling offers a significant advantage in situations where researchers face financial and resource constraints, particularly when studying populations distributed across diverse geographical locations. In such contexts, this method can efficiently produce the required data while reducing costs and logistical demands associated with sampling individual units. (Taherdoost, 2016a). Convenience sampling differs from probability-based sampling approaches. As the term suggests, convenience sampling refers to

the selection of participants based primarily on accessibility and ease of recruitment, rather than randomisation. In some contexts, mixed or multi-method sampling strategies may be employed to address a research question by combining different sampling techniques. Such approaches can be used to obtain a diverse range of sample characteristics, thereby capturing various combinations and permutations of complex sampling structures (Teddle and Yu, 2007a; Taherdoost, 2016a). This research adopted stratified random sampling. This is primarily due to the need for the study to interrogate the levels of adaptability of digitalisation tools across various cidb graded contractors in South Africa.

4.5.3 Sample size for the study

It is statistically impossible to distribute the research instrument across the entire populous of interest or target population of the study. Additionally, a series of confounding factors exist in the event of attempting such a quest. As a result, a technique which can aid in selecting a portion of the target population in order to draw a conclusion regarding the phenomena being researched, is crucial for testing of the hypotheses and addressing the objectives of the study (Lohr, 2021). A research sample for the study is established to determine the number of participants required. The establishment of the research sample is often confronted with critique pertaining to rigor and practicality. It thus must be noted that a determination of a desired confidence interval, level of statistical significance, margin of error, and probability of goodness of the sample is determined (Blair *et al.*, 2013). Cochran (1977) proposed a formula that incorporates all these variables to determine a sample size. This study adopts the same technique in determining the sample size using the variables established. A 95% confidence interval with a 5% significance level is applied for this study. Additionally, a 5% margin of error is observed. Equation 4.1 presents the calculation of the sample size. Construction companies classified within Grades 4 to 9 were identified from the cidb registry. Accordingly, this study intends to engage participants from these organisations in order to test the study's hypotheses. However, a simplified calculation of the sample size is required, and it is detailed in the three equations (Equation 4.1 – Equation 4.3) presented.

Where:

ss = sample size

z = this is the value that corresponds to the confidence interval

p = percentage picking a population choice (0,5)

c = represents the margin of error

$$\begin{aligned}
 ss &= \frac{z^2 p(1-p)}{c^2} && \text{Equation 4.1} \\
 &= \frac{(1,96)^2 \times 0,5 (1 - 0,5)}{(0,05)^2} \\
 &= 384,16
 \end{aligned}$$

A further adjustment to the sample size is necessary to ensure a fair and representative sample for the study, thereby ascertaining the study's standardised generalisability.

$$\begin{aligned}
 \text{New ss} &= \frac{ss}{1 + [(ss-1)/N]} && \text{Equation 4.2} \\
 &= \frac{384,16}{1 + [384,16 - 1]/238} \\
 &= 147,19
 \end{aligned}$$

Ss = sample size

N = targeted population

However, according to Bowling (2005) and Manfreda *et al.* (2008), an innate concern with online or self-administered questionnaires is that participants tend not to complete answering the questionnaires, and as a result this yields a lower number of the sample size. Furthermore, this is an endemic concern in the construction industry when conducting research. As a result, to make consideration for the participants who may not answer the questionnaire or provide an incomplete response, a general assumption adopted for this study is that, at least 30% response rate is expected as per the general nature of the construction industry and the observed response rates across research (Baruch, 1999; Manfreda *et al.*, 2008; Lohr, 2021). The sample size that the study envisage to reach is thus worked out as follows.

$$\begin{aligned}
 ESS &= \text{New ss} / 30\% && \text{Equation 4. 3} \\
 &= 147,19 / 0,3 \\
 &= 490,64
 \end{aligned}$$

ESS = Expected Sample Size for the study

The other analysis, which was used to determine the sample size for this study, was conducted using the SurveyMonkey sample size calculator (<https://www.surveymonkey.com/mp/sample-size-calculator/>). Similar to the conditions stipulated above, where a confidence interval of 95% is applied with a margin of error of 5%, the calculated sample size was 339. As a result, for this study, it was expected that the sample size The expected sample size for the study is 339 as it is based on a known population and calculated with that as a definitive numerical output.

4.6 Methods of data collection

Data can be collected in a plethora of ways and this is largely dependent on the nature and type of data of interest to the study (Rhodes *et al.*, 2003; Creswell, 2009). The limitations and conditions circumventing the extraction of data follows the same rhetoric in that the nature and type of data, can be limited and marginalised by conditions around the science of interest, particularly the population of interest. Notwithstanding this, integrating quantitative and qualitative methods of analysis has the potential to facilitate easier access to and utilisation of data (Rhodes *et al.*, 2003). Additionally, this integration innately commands various techniques of collecting the said data for the purpose of addressing the research question and allows ease of elimination for techniques which fall out of the scope of the research (Rhodes *et al.*, 2003; Evans and Mathur, 2005). The two datasets follow a rigorous and comparable data collection process designed to ensure confidentiality while enabling the extraction of relevant information for analysis using various analytical tools. In addition, the data is handled with appropriate care to prevent the identification of affiliated companies with which respondents are associated in the study (Davis, 1999). As a result, it is essential to analyse the methodology adopted for this study in acquiring/collecting both quantitative and qualitative data.

4.6.1 Methods of data collection – Quantitative component

Ethical clearance for the study was obtained in April 2024, and data collection commenced immediately after, from April 2024 to December 2024 (9 months). Before ethical consideration (and subsequent approval), rigorous consultation meetings were held between the researcher and the supervisor. The fundamental basis of these meetings at that stage of research was to ensure that the questionnaire was succinct, unambiguous, rigorous and poignantly anchored all

the attention and focus on addressing the research objectives. This stage served as the piloting component of the study as input was also gathered from colleagues, research group participants and industry acquaintances to ensure that the questionnaire was fair and well-paced. A significant factor that the design of the questionnaire aimed to address was the response time with which the participants could complete the questionnaire. This emerged as an important consideration, as one had to be cognisant of the fact that the intended population may not have the luxury of time or the patience to undertake or complete the questionnaire on time (Rhodes *et al.*, 2003; Bowling, 2005). This consideration was primarily due to the nature of construction industry where the dynamism of the various projects (and activities) have different demands which can impede participation (Meintjes *et al.*, 2007). It was determined that the average time it took to complete the questionnaire was 25 minutes uninterrupted.

As can be seen in Appendix B.2, the questionnaire was administered to companies that are on the cidb registry between the Grades 4 - 9. Furthermore, the demographic of participants spanned company directors, contract managers, project managers, site agents, construction managers, quantity surveyors, estimators and cost engineers. The primary reason for the selection of these professionals is due to their direct involvement in the procurement, design and utilisation of digital technologies the study aims to assess. The questionnaire was distributed through Survey Monkey platform. The questionnaire is separated into four (4) distinct sections, which makes it convenient for the respondents. The first section collects the general information of participants, with their identities concealed and coded through the aggregated analysis process. The second section focuses on technical information that is more geared towards the varying types of technologies adopted and implemented on construction projects. The third section deciphers the fundamental barriers that affect the inability of the construction companies to either adopt or implement digital technologies. Lastly, the fourth section draws the focus of the respondents on the potential enablers that either the construction firms, legislative amendment or government has done or can do to ensure the ease of both implementation and adoption of digital technologies (Appendix B.2).

The questionnaires distribution through online platform is considered a cost effective and efficient methods of data collection. This is mainly due to the ability to reach a wider populous (Rhodes *et al.*, 2003). This stands to be a significant advantage for this study as the research respondents are based in the nine (9) South African provinces. Notwithstanding that, Rhodes

et al. (2003) further reiterate that an online-administered questionnaire has a high probability of ensuring a quick response. This is further postulated by Evans and Mathur (2005) in asserting that this form of administration provides respondents a comfortable (convenient) time to undertake the study at their own accord without any disruptions. Furthermore, when participants are in their comfortable environments, the probability of them responding truthfully is amplified as opposed to the adverse where they must respond on the spot under time limitations (Fricker and Schonlau, 2002; Rhodes *et al.*, 2003; Creswell and Clark, 2017b; Nayak and Narayan, 2019). Moreover, literature promotes the administration of questionnaires through the web as the cost of distributing, collecting and analysing the data is significantly low (Fricker and Schonlau, 2002; Nayak and Narayan, 2019). Thus, for the aforementioned premise, distributing the questionnaire and collecting it with the use of the web, particularly with low uptake costs of administration made this route a convenient one for this study. However, it is also crucial to address some of the impediments this method can have on the collection of data.

An often disregarded variable in online distribution of a questionnaires, is the assumption about the respondents' level of literacy which is largely contingent on one's ability to read, comprehend and reply from the basis of understanding (Bowling, 2005). Minimal consideration of this factor when designing and distributing the questionnaire has the propensity to distort the data collected and inversely not provide a holistic perception of the respondent's feedback. Manfreda *et al.* (2008) purports that, compared to traditional methods of collecting data, online/web surveys yield 11% response rate among participants of interest. This is further expanded by alluding that some of the reasons attributed to this low rate of response is the respondents assumption that the barrage of emails sent to them to participate in the study may be spam (Evans and Mathur, 2005; Manfreda *et al.*, 2008). This thus provide less confidence in the responses collected and the analysis thereof.

4.6.2 Methods of data collection – Qualitative component

As opposed to the self-administered portion of the study which was conducted through the distribution of the research questionnaire, the qualitative component was administered through semi-structured interviews. A semi-structured interview schedule was drawn and through the approval of the supervisor for its rigor and detail orientated nature, administered through a specifically selected group of participants. There is no significant difference between the

questionnaire schedule and the interview schedule. The interview schedule consisted of open-ended questions, which are presented in Appendix C. The objective of these types of questions was to foster an unrestricted provision of information from participants. Furthermore, a researcher could identify new data that may not have been envisaged from the outset of the study or considered in the design of the questionnaire schedule (Creswell and Clark, 2017b; Adeoye-Olatunde and Olenik, 2021; Karatsareas, 2022). Additionally, through this form of data gathering method, an open dialogue was created between the researcher and the participants, and as a result, an extensive probe of some of the responses instituted for a more in-depth analysis. As per the ethical considerations, all participants consented to be part of the study by signing the consent form before answering the research questions.

Eleven (11) interviews were conducted through Microsoft Teams. The utilisation of this tool was to allow meeting sessions to be recorded in audio format for easy access as well as to have the meetings transcribed for ease of access should a need arise, particularly to ensure that no information is omitted. Three (3) of the interviews were conducted in person and the recording was transcribed. Adopting this research approach, enhanced the depth and vastness of data provided as this added a nuanced perspective across the participants lived industry experiences. Additionally, this provided the researcher the opportunity to conduct a thorough analysis of the data.

4.6.3 Methods of Data Analysis – Quantitative

The quantitative analysis component of the study comprised a significant number of constructs, and the envisaged hypotheses to be tested, aimed to establish relationships across these constructs and independent variables. It was thus necessary to explore multiple data analysis methods to achieve this. It is imperative to distinguish the various statistical analysis tools employed. For the quantitative component of the research, the three main data analysis tools used were partial least squares structural equation modelling (PLS-SEM 4). PLS-SEM 4 was utilised for its ability to conduct reliable tests in the event that a test for a theoretical framework is required (Hair *et al.*, 2019; Purwanto and Sudargini, 2021; Usakli and Rasoolimanesh, 2023). Notwithstanding that, this objective is the foundation of this study. Additionally, this model is utilised due to the complexity and the many constructs involved in the study. Another data analysis tool used was IBM SPSS. This software comprises a combination of limitless methods

of data analysis tools which are fitting to both nonparametric and normally distributed data (Mallery and George, 2005). Another tool used to analyse data was Microsoft Excel particularly in the presentation, validating standard deviations, RII, MIS and ranking constructs. The Relative Importance Index (RII) and Mean Item Score (MIS) were employed to assess the ranking of the constructs across respondents, with the aim of determining their relative levels of significance and thereby identifying those with the greatest and least impact (Fugar and Agyakwah-Baah, 2010; Azman *et al.*, 2019). The research hypotheses were analysed through the use of PLS-SEM model, Kruskal-Wallis test and Spearman Rho. The other data analysis techniques included the use of frequencies, percentages and standard deviations. Table 4.2 expresses the various hypotheses tested for this study and how each is tested. This table shows analytical method most fitting to understand and evidence the relationship which exists across constructs. The analytical tools were used to test and validate the hypotheses.

Table 4. 2: Hypothesis-analysis mapping table.

Hypothesis	Constructs	Data Type	Analysis tool
H1	Digitalisation and Productivity	Quantitative	PLS-SEM/Kruskal-Wallis/ Spearman Rho
H2	Digitalisation and Contextual factors (Environmental/Organisational and Technical factors)	Quantitative	PLS-SEM/Kruskal-Wallis
H3	Digitalisation and Skill	Quantitative	PLS-SEM/Kruskal-Wallis

4.6.4 Methods of Data Analysis – Qualitative

The analysis of qualitative data followed a sequential process delineated by (Creswell, 2009) when conducting an analysis from a recorded medium which requires transcription. The NVivo 15 was used in analysing the qualitative data component of this study. However, before this software was adopted for use, it is imperative to detail the collection of data and how it was structured in order to be analysed. Interviews were conducted with participants through an online interface or an in-person format. In both formats, consent was granted from respondents and as a result, all the conducted interviews were recorded before transcription. Moreover, the first phase of the analysis of data was conducted across the online interviews, which were done using MS Teams. The functionality to record and transcribe significantly decreased the time to

transcribe. During the data cleaning, which was the second phase of the analysis, filler words and repeated words were removed before the transcripts were loaded into NVivo 15 for analysis. According to Riger and Sigurvinsdottir (2016), immersion into the data gathered is a crucial step in understanding and structuring of a thematic analysis, and this was observed for this study. More importantly, the repeated iterations of ensuring the data captured is critical to addressing the research objectives and answering the research questions, conspicuous word identification was executed. Similarly, the in-person interviews were recorded, and the transcription was conducted in the same format of re-reading and omitting filler and repeated words. At this stage, NVivo 15 was identified as an analytical tool characterised by methodological rigour and its capacity to manage complex datasets (Limna, 2023). This analysis tool provided the capacity to streamline and enhance the quantitative data presentation for presentation and interrogation. A notable preference of the analysis is the ease with which data can be coded, categorised according to themes, and perform cross-analysis (Elliott-Mainwaring, 2021; Dhakal, 2022). The emergent of themes which were created through NVivo 15, provided the researcher contextualisation and areas significantly impacted when drawing conclusions for the study (Dhakal, 2022). These themes were named according to the consistency of occurrence across a construct; as a result, eight (8) core themes were established. The cross-analysis reporting of the data can be retrieved in the form of figures, word trees, or word cloud (Limna, 2023). The selection of this analytical tool enables the researcher to either develop codes independently or derive codes directly from the provided data. This functionality facilitates data validation, particularly in instances where a construct is absent or insufficiently operationalised within the existing coding framework (Allsop *et al.*, 2022). Therefore, this is the analysis method used in analysing the qualitative component of the data collected.

4.7 Validity

A consensus exists across the social sciences that ascertaining validity in research is paramount to the study's generalisability. In other research contexts, validity refers to the extent to which a study's findings accurately represent the phenomenon under investigation and truthfully reflect the data collected. Additionally, this also refers to how variable precision is achieved when analysed in context of the population under which the study is conducted (Cahit, 2015). However, there are two critical components of validity that must be probed further in establishing a complete validity benchmark of a study's output and confirmation of research instrument. These components are internal and external validity.

4.7.1 Internal Validity

Internal validity is referred to as the degree to which a study can ascertain a causal relationship or correlation between variables tested in a study (Franklin and Ballan, 2001; Kimberlin and Winterstein, 2008; Saunders, 2009; Taherdoost, 2016b; Sürücü and Maslakci, 2020). Creswell (2011) corroborates this in postulating that the prospect of cause and effect in internal validity, further allows the researcher to understand variables accurately in order to deduce the existence of correlation or lack thereof. Additionally, in assessing the relationship across variables, it is imperative to critically analyse if the results of the research are as a consequential output of the variables studied or the externalities devoid of significance to the study (Cahit, 2015; Taherdoost, 2016b). However, literature further elaborates on the concept of validity by asserting that construct validity, content validity, and criterion validity are equally significant in research. Each form of validity contributes to the robustness of the measurement process, ensuring that the study is methodologically sound and that the variables under investigation are measured accurately and legitimately. Collectively, these forms of validity enhance the quality, credibility, and overall integrity of the research findings (Cahit, 2015; Taherdoost, 2016b; Sürücü and Maslakci, 2020).

4.7.2 External validity

External validity refers to the extent to which the findings of a study can be generalised beyond the research setting. This includes applying the results to the wider population, different geographical locations, or similar industries and organisations operating in different environments while maintaining the relevance and applicability of the study's conclusions (Franklin and Ballan, 2001; Sürücü and Maslakci, 2020). Findley *et al.* (2021) further posits that validity allows inference to be drawn onto a larger population from the findings of a study. It is however argued that the determinant of validity is the meaningful interpretation of the data obtained. Furthermore, the perception of external validity is centred around the appropriateness of how the interpretation of data enhances generalisability, thus ensuring that data analysis is conducted in a methodical manner with careful attention.

4.8 Reliability

The research instrument proposed for this study is one of the most significant components and its legitimacy and rigor must uphold the quality and consistency of the research. Reliability

is a fundamental criterion for ensuring the rigor of a research instrument. It is commonly defined across literature as the extent to which a data collection instrument consistently produces similar results when the same instrument, analytical procedures, and testing methods are replicated in different studies or across varying contexts. A reliable research instrument therefore demonstrates stability and consistency, thereby enhancing credibility and trustworthiness of the research findings (Morse *et al.*, 2002; Golafshani, 2003; Kumar, 2014; Saunders *et al.*, 2015; Sürücü and Maslakci, 2020). In designing the research instrument, the consistency, accuracy as well as the firmness of the research instrument are the strata upon which data collected can aid in answering the research question. One of the core variables of ensuring reliability for this study, was the intensive consultation with the supervisor. This was to ascertain that the research instrument is not ambiguous in language, and that the length of the questions is appropriate for the target population (sample size). Another aspect considered in ascertaining the reliability of the study was management of bias. The research instrument (questionnaire) was administered via the SurveyMonkey platform, thereby ensuring that the researcher had no capacity to alter or adjust participant responses. All responses were captured automatically by the platform, which facilitated data integrity and minimized the potential for researcher interference during the data collection process.

Table 4. 3: Cronbach's Alpha values for digital tools (software and technique)

Disruptors	Name of digital tool (software or technique)	Cronbach's Alpha Value
Software based digital tools.	Augmented Reality (VR)	0,916
	Building Information Software (BIM)	
	Information and Communication Technology (ICT)	
	Web Based Project Management (WBPM)	
	Big Data and Analytics	
	Internet of Things (IoT)	
	Virtual Reality (VR)	
	Blue Beam Software	
	Cloud Computing	
	Virtual Prototyping	
	Wireless Sensor Network (WSN)	
Integration across software based and tangible form of digital technologies.	Digital Twins	0,873
	Production Robots (Robotics)	
	3D Printing Machines	
	Drones / Scanning Drones	
	Modular Construction	
	Mobile Devices (smart and handheld devices)	
	Wearable Device (such as motion sensors and digital transmitters)	
Combine Cronbach's Alpha	Software based and tangible form of digital technologies	0,945

The reliability and internal consistency of the variables used in this study were assessed using Cronbach (1951) statistical measure, which is specifically designed to evaluate the homogeneity of items within a construct. In developing this statistical tool to measure consistency, Cronbach (1951) posits that the value of Cronbach's alpha (α) must pivot between the range 0 - 1. Furthermore, the degree of significance of α can be split into three categories. The first category is that if $\alpha < 0,5$ the consistency across variables is poor and as a result, not reliable. The second category is that if $0,7 \leq \alpha \leq 0,9$, the data set is considered to be consistent and α is acceptable. Lastly, if a condition that $\alpha > 0,9$ is observed, the data set is considered to be very reliable with an excellent α value. As a result, Cronbach's Alpha test was adopted as a reliability testing technique for this study as it was one of the tests used to ensure internal consistency across study variables (Cronbach, 1951; Warrens, 2014; Bonett and Wright, 2015). Moreover, Pallant (2020) and Mallery and George (2005) postulate that α values above 0,7 are widely accepted and evidence an acceptable consistency from a scientific perspective. Cronbach's alpha was generated for this study, and Table 4.3 presents the results across software based digital tools ($\alpha = 0,916$), and integration across software based and tangible form of digital tools ($\alpha = 0,873$).

Table 4. 4: Cronbach's Alpha values for External factors (environmental, organisational/construction firm and technical factors)

External Factors - Categorisation	Name of the factor	Cronbach's Alpha Value
Environmental Factors.	Inclement weather (rain/cold/heat)	0,902
	Unexpected site ground conditions	
	Site location/environment	
	Lack of experience amongst workers	
	Delays in delivery of material	
	Uncertain Ground conditions (soil type)	
	/Uncertainty in terrain	
	Poor site supervision	
	Lack of tools and equipment	
	Mismanagement of resources on site	
	Rework due to poor quality	
Organisational/Construction Firm.	Non-payment of labour	0,900
	Delays in payment of labour	
	Fluctuations in material/equipment prices	
	Changes in management structure	
	Shortage of labour/manpower	
	Inexperienced supervisors	

	Lack of training on new skills	
	Change in government legislature/policy	
	Economic changes (change in VAT, inflation and foreign exchange rates)	
Technical Factors.	Poorly designed project	0,939
	Lack of Digital Software	
	Absence of digital collaboration amongst professionals	
	Incomplete drawings	
	Methods of construction (prefabrication vs onsite)	
	Poor co-ordination/planning of activities	
	Complexity of the project	
	Lack of Automation (robotics)	
	Buildability of the structure	
	Inspection delays from engineers	
	Change orders from the designers/consultants	

As a result, the variables for this research instrument are consistent and accepted. Table 4.4 presents the α values for external factors where environmental factors ($\alpha = 0,902$), organisational/construction firm factors ($\alpha = 0,900$) and technical factors ($\alpha = 0,939$) are calculated and accepted as reliable and yielded an excellent α value.

4.9 Handling missing data

Missing data is one of the main concerns which affects the quantitative component of data analysis. This is predominantly observed when statistical computations are performed for data analysis. Moreover, this has the ability to negatively affect the findings of if not handled well, especially with scientific and pragmatic methods (Berchtold, 2019; William, 2024). According to Berchtold (2019), 69,5% of published papers are found to comprise missing item-level data. Furthermore, it is found that in these instances, the method of deletion creates bias across the findings as it reduces the statistical rigidity of a study. This study adopted Expectation Maximisation (EM) as an appropriate and scientifically proven method of handling missing data. According to (Zhang *et al.*, 2014), EM is a method which performs multiple iterations over a selected data set comprising missing variable-values in order to estimate unit quantifiers for missing value across an established scale to allow analysis to be conducted with ease. This study utilised IBM SPSS to perform this iteration and the report is presented in Appendix J. Ensuring statistical rigor and minimizing researcher bias were essential considerations for this study; consequently, EM algorithm was identified as the most appropriate method for data

handling.

4.10 Ethical Considerations for the study

This study involves the collection of sensitive information, which may pose potential risks to participants in the event of improper handling, unauthorized disclosure, or non-compliance with the University of Cape Town's Data Management Plan (DMP) regarding data storage and management. As a result, significant caution must be placed on the anonymity of respondents by not revealing their names, companies they are affiliated with or any form of identifier which can be traced. In answering the questionnaire through Survey Monkey platform, respondents will have the first page of the questionnaire detail consent to their voluntary engagement in the study, as well as guaranteeing them anonymity of data provided, as well as the handling of data so as to not, at any point, jeopardise their participation in the study. The consent form will further explain and ascertain the respondents of the choice to revoke participation in the study at any point should they want to do so. This revocation will expressively be explained that it will be without impunity or any form of punishment as participation in the study is voluntary. Moreover, the research acknowledges potential harm that may emanate from findings, as an ethical consideration, the reporting of data will not include any names of the respondents or organisations they are affiliated with. The commencement of data collection for this study is contingent upon obtaining ethical clearance from the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town (UCT). In addition, the study's findings will be archived in the UCT institutional repository in accordance with the Data Management Plan (DMP).

4.11 Chapter Summary

This chapter delineates a chronological order followed of selecting a research strategy applicable for this study. Additionally, various aspects that ascertain scientific and methodical rigor to addressing the research hypothesis, are detailed and explained in detail. A research paradigm depicting the synthesis of the research methodology is elucidated through Saunders (2009)'s research onion. A research approach adopted for this study is explained in detail wherein it is stipulated that the research proposes to adopt a mixed method approach. This is where both the quantitative and qualitative approaches are to be adopted for the study. The combination of the two is to have the weakness of the one approach is supplemented by the strength of the other. Additionally, the qualitative approach is to ensure that a deeper

understanding of the research constructs is achieved through interviews with the research participants. Research strategy is elaborated and the systematic order in which both the quantitative and qualitative components of the study are to be conducted, is comprehensively explained. Central to the study is the population, sample selection and the actual sample size. These three proponents of the study are explained and identified in great detail where the target population is identified and the sample and sample size for the study are calculated through the use of equations (Eq.1 – Eq.3). In light of the study adopting a mixed method, the two different types of data collection methods are detailed together with the various data analysing tools to be used. Furthermore, the validity and reliability of the research data is delineated with the respective statistical tests performed on the research data's reliability and validity. The management of the missing values in the data set was addressed using Expectation Maximisation (EM) as a rigid and reliable method. Lastly, a synopsis of ethical factors to be considered in the study is explained as well as the management of bias for the study. As a result, this chapter thoroughly detailed the research methodology adopted for this study and encompassing factors.

CHAPTER FIVE: QUANTITATIVE DATA PRESENTATION AND ANALYSIS

5.1 Introduction

This chapter presents the quantitative data component of the research. The presentation of quantitative data is split into three components which is reporting the data, analysing the data and hypothesis testing which includes all the statistical analyses and interpretations. Additionally, this chapter presents data across all the respondents collected from Grade 4 - 9 cidb graded contractors in South Africa who specialise in general building (GB) and civil engineering (CE). The data presented represent the aggregated valid responses obtained following the cleaning and sorting of the collected data according to response completion status. Furthermore, this chapter presents the split in participant responses across personal reported information, organisational based responses, as well as construction project centred responses pertinent to the digital technologies used on projects and their perception on the impact of the variables on the construction project. Lastly this chapter present the hypotheses test results and analysis.

5.2 QUANTITATIVE PRESENTATION OF DATA

5.2.1 Background Information of the respondents

Table 5.1 presents the demographic data of the respondents. When observed across the age range, Table 5.1 reports that 1% of the respondents reported to have less than 25 years of age as opposed to 8% of the respondents who reported to be above the age of 65. However, a proportionate of the respondents reported to have between 34 – 44 years of age which equated to a 33% of the response rate. Similarly, 34% of the respondents were found to be between 45 - 54 years of age. According to academic qualifications, most respondents are in possession of BSc/BEng/Diploma, and this is represented by a 40% margin across responses. About 20% of the participants are in possession of MSc/MBA qualification where 5% have reported to have obtained a PhD. However, not all respondents fell within the provided options set out in the research instrument, and these participants constitutes 13% of the total responses. They do however report to be in possession of a Certificate in Adult Basic Education and Training (ABET), trade certification from technical colleges, National higher diploma civil engineering and National higher diploma in construction management and control civil engineering.

Table 5. 1: Respondents Personal Profile.

	Age Range	Coding number	Frequency	Percentage
	Less than 25 years.	1	1	1%
	Between 25 - 34 years.	2	5	5%
	Between 34 - 44 Years.	3	30	33%
	Between 45 - 54 years.	4	31	34%
	Between 55 - 64 years.	5	18	20%
	Above 65 years.	6	7	8%
Total		-	92	100%
	Academic Qualification	Coding number	Frequency	Percentage
	BSc/BEng degree/Diploma.	1	37	40%
	Honors/BTech degree.	2	20	22%
	MSc/MBA.	3	18	20%
	PhD.	4	5	5%
	Other	5	12	13%
Total		-	92	100%
	Years of Experience in the Construction industry	Coding number	Frequency	Percentage
	Less than 5 years.	1	1	1
	Between 6 - 10 years.	2	11	12
	Between 11 - 15 years.	3	23	25
	Between 16 - 20 years.	4	20	22
	Between 21 - 30 years.	5	26	28
	More than 30 years.	6	11	12
Total		-	92	100%

Table 5.1 further presented the number of years the respondents have in the construction industry. A reported 28% of the respondents have between 21 – 30 years of construction industry experience whereas 1% has less than 5 years construction industry experience. It is further noted that 12% of the respondents have more than 30 years of construction industry experience. Through the data collection period, the current job role of most participants were project managers, contract directors and construction managers and these constituted a portion of 26%, 24% and 17% respectively across responses. It was imperative to examine the type of project in which respondents were currently engaged, particularly to understand the demand for and need of digital technological tools. This is presented in Table 5.2 where 43% of the respondents engaged in General Construction and Built as opposed to 18% of respondents employed in Road developments.

Table 5. 2: Respondents Personal Profile (Continued...)

	Designation/Job Description	Coding number	Frequency	Percentage
	Director Cadre	1	46	50%
	Contracts Manager	2	7	8%
	Project Manager	3	16	17%
	Site Agent	4	2	2%
	Construction Manager	5	6	7%
	Site Engineer	6	0	0%
	Construction Supervisor	7	0	0%
	Quantity Surveyor	8	8	9%
	Estimator	9	1	1%
	Cost Engineer	10	1	1%
	Other	11	5	5%
Total		-	92	100%
	Current Job Role	Coding number	Frequency	Percentage
	Construction Manager (CM)	1	16	17
	Contracts Director	2	22	24
	Contracts Manager	3	9	10
	Project Manager (PM)	4	24	26
	Quantity Surveyor (QS)	5	8	9
	Civil Engineer/Structural Engineer	6	8	9
	Architect	7	2	2
	Mechanical Engineer	8	1	1
	Other	9	2	2
Total		-	92	100%
	Type of Project Currently working on.	Coding number	Frequency	Percentage
	High End Housing project	1	3	3
	Infrastructure (building)	2	16	17
	Road developments	3	17	18
	General Construction and Built	4	40	43
	Refurbishment Project	5	0	0
	Airport	6	1	1
	Railway Development/Roads	7	1	1
		8	14	15
Total		-	92	100%
	Current Project Location in South Africa	Coding number	Frequency	Percentage
	Mpumalanga	1	7	8
	Limpopo	2	6	7
	Gauteng	3	37	40
	North-West	4	2	2
	Free State	5	6	7
	Kwa-Zulu Natal	6	11	12
	Northern Cape	7	3	3
	Eastern Cape	8	2	2
	Western Cape	9	18	20
Total		-	92	100%

5.2.2 Organisational background information of respondents

Table 5.2 presents the geographical location of the respondents and related geography of the projects they currently oversee. It can be observed that a significant proportion of respondents are located and operate in Gauteng Province (40%), followed by Kwa-Zulu Natal (12%), Mpumalanga (8%) and both Limpopo (7%) and Free State Province (7%). The least proportion of collected responses which are based and operate in the construction industry were collected

from Northern Cape (3%) and the Eastern Cape (2%) respectively. It must be noted that during the period of data collection window, some responses from participants fell within the cidb categorisation of grade 1 to grade 3. These responses were excluded from the study and, consequently, were not included in the data analysis. For the purpose of this study and analysis, only contractors within the category of grade 4 to grade 9 were analysed. This is presented in Figure 5.1 which provides a composition split of the organisations considered for the study. Additionally, Figure 5.1 also presents the split in contractor involved in general built and those involved in civil works.

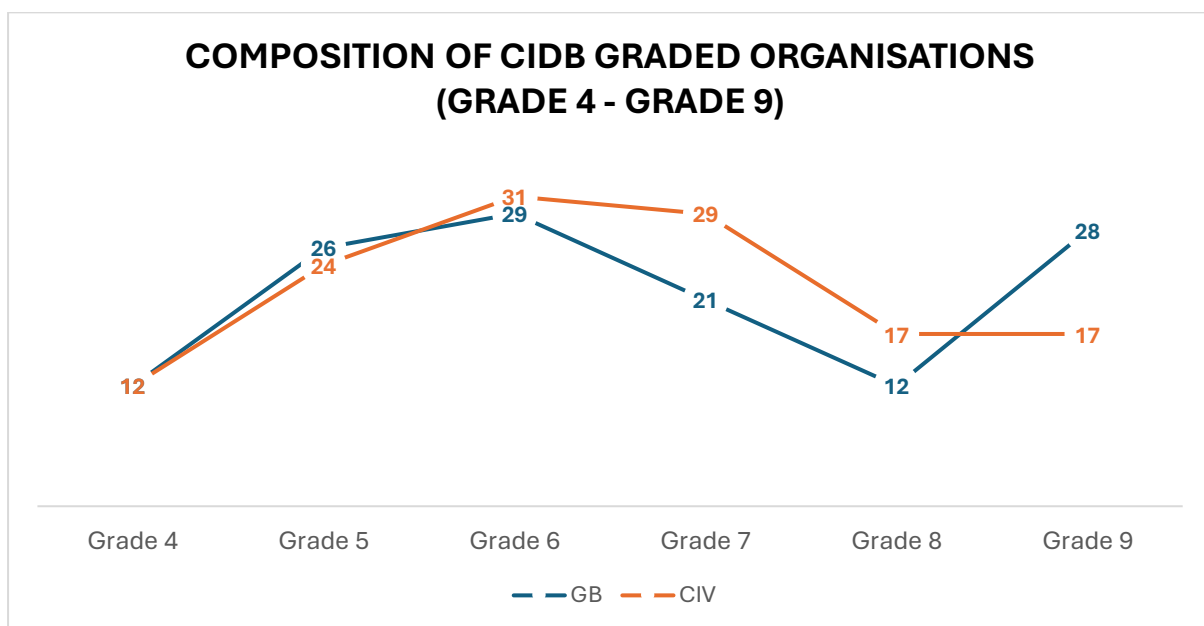


Figure 5. 1: CIDB grade affiliation of the respondents.

5.2.3 Evaluation of digital technologies utilised across projects

The fundamental objective of this research was to establish and determine the types of tools and digital technologies being engaged in the South African construction industry. Table 5.3 presents a synthesis of the digital tools identified through an extensive analysis of the research results, together with their degree of perceived adoption and impact on the construction industry processes. These tools are assessed across three integral levels of a construction project which are planning, design and the construction development process. These tools are coded DT (Digital Tools) and range from DT1 to DT18. Table 5.3 presents the results of the analysis of these digital tools assessed through the use of MIS. Mobile Devices (smart and handheld devices) (MIS = 0, 739) is ranked the most widely used form of innovation in the

construction industry. Information and Communication Technology (ICT) (MIS = 0,659) is ranked second, whereas Internet of Things (IoT) (MIS = 0,559) and Building Information Software (BIM) (MIS = 0,549) are ranked third and fourth respectively for being most significant digital tools used in the industry. It can also be observed that Web Based Project Management (WBPM) (MIS = 0,520) is ranked in the fifth position across the eighteen forms of digital tools inquired. However, the analysis show that Blue Beam Software (MIS = 0,354) and Production Robots (Robotics) (MIS = 0,302) are the least used forms of digital tools used in the South African construction industry.

Table 5. 3: Different types of digital technologies used in the construction industry.

Coding Label	Type of Digital Technology	Σw	SD	MIS	Rank (R)
DT13	Mobile Devices (smart and handheld devices)	82	1,513	0,739	1
DT3	Information and Communication Technology (ICT)	81	1,512	0,659	2
DT6	Internet of Things (IoT)	82	1,585	0,559	3
DT2	Building Information Software (BIM)	82	1,647	0,549	4
DT4	Web Based Project Management (WBPM)	82	1,514	0,520	5
DT15	Cloud Computing	82	1,448	0,517	6
DT10	Drones/Scanning Drones	82	1,325	0,466	7
DT5	Big Data and Analytics	82	1,361	0,444	8
DT12	Modular Construction	82	1,407	0,437	9
DT11	Virtual Reality (VR)	82	1,245	0,427	10
DT18	Wireless Sensor Network (WSN)	82	1,395	0,427	10
DT17	Wearable Device (such as motion sensors and digital transmitters)	82	1,304	0,410	12
DT1	Augmented Reality	82	1,290	0,407	13
DT16	Virtual Prototyping	82	1,343	0,400	14
DT9	3D Printing Machines	82	1,324	0,395	15
DT7	Digital Twins	82	1,311	0,380	16
DT14	Blue Beam Software	82	1,210	0,354	17
DT8	Production Robots (Robotics)	82	1,080	0,302	18

SD: standard deviation; Σw : weighted total; MIS: Mean Item Score; R: rank.

5.2.4 Acquisition, expertise and training required competencies in digital utilisation

In the analysis of. Perception of levels of skill, knowledge and expertise essential to the to the adoption of digital technologies in the construction industry, the research wanted to understand how this is either considered or integrated as a key proponent across the construction industry. Table 5.4 report of the perceived perception of significance of stakeholder's acquisition of

skills and knowledge in the utilisation of digital tools in the construction industry. Knowledge and familiarity in the use of Mobile Devices (smart and handheld devices) (MIS = 0,677) is perceived to be the most significant digital tool to be acquainted with; this is followed by Information and Communication Technology (ICT) (MIS = 0,600); Web Based Project Management (WBPM) (MIS = 0, 545); Internet of Things (IoT) (MIS = 0,526), and Cloud Computing (MIS = 0,523). However, production robots (Robotics) (MIS = 0,339) is a kind of digital tool not perceived to have any significance with regards to the required expertise as well as training necessary to be used in the South African construction industry.

Table 5. 4: Perception of skill and training required in digital adoption.

Coding Label	Type of Digital Technology	Σw	SD	MIS	Rank
DT13	Mobile Devices (smart and handheld devices)	62	1,497	0,677	1
DT3	Information and Communication Technology (ICT)	62	1,343	0,600	2
DT4	Web Based Project Management (WBPM)	62	1,416	0,545	3
DT6	Internet of Things (IoT)	62	1,382	0,526	4
DT15	Cloud Computing	62	1,43	0,523	5
DT2	Building Information Software (BIM)	62	1,376	0,506	6
DT12	Modular Construction	62	1,405	0,474	7
DT10	Drones/Scanning Drones	62	1,372	0,458	8
DT1	Augmented Reality	62	1,298	0,445	9
DT11	Virtual Reality (VR)	62	1,349	0,435	10
DT18	Wireless Sensor Network (WSN)	62	1,353	0,429	11
DT5	Big Data and Analytics	62	1,248	0,426	12
DT9	3D Printing Machines	62	1,38	0,423	13
DT17	Wearable Device (such as motion sensors and digital transmitters)	62	1,258	0,416	14
DT16	Virtual Prototyping	62	1,213	0,413	15
DT7	Digital Twins	62	1,186	0,387	16
DT14	Blue Beam Software	62	1,197	0,381	17
DT8	Production Robots (Robotics)	62	1,139	0,339	18

SD: standard deviation; Σw : weighted total; R: rank.

5.2.5 Risks associated with the adoption of digital technologies across projects in South Africa

It was also imperative to assess and obtain a comprehensive understanding of the fundamental factors that act both as deterrents or threats capable of hindering successful adoption of digital tools, an analysis of external factors was also important for the study. These deterrents or threats are considered external factors which exists either outside the control of the construction

environment or organisational control. These factors are sub-divided into three categories: environmental, organisational and technical factors. Table 5.5 to Table 5.7 report the findings through the utilisation of the relative importance index (RII), standard deviation (SD) and rank (R) in order to show most significant of threat to adoption of digital technologies.

5.2.5.1 Environmental factors

Table 5.5 shows the perceived environmental factors with the most significant impact on the adoption of digital technologies across construction projects in South Africa. These factors are coded EF (environmental factor) and they range from EF1 to EF10. As can be seen in Table 5.5, Inclement weather (rain/cold/heat) (RII = 0,811) is considered a significant factor to consider in the implementation of digital tools and poses a great threat in the adoption and mechanisation of a construction project; this is followed by Delays in delivery of material (RII = 0,757); Unexpected site ground conditions RII = 0,754); Poor site supervision (RII = 0,751), and Site location/environment (RII = 0,711). The analysis does show that Rework due to poor quality (RII = 0,699) is not considered a very significant factor across environmental factors as it was ranked last across EF tested.

Table 5. 5: Impact of environmental factors to consider in the implementation of digital technologies on construction projects.

Coding Label	Environmental Factors	SD	RII	Rank (R)
EF1	Inclement weather (rain/cold/heat)	1,054	0,811	1
EF5	Delays in delivery of material	1,162	0,757	2
EF2	Unexpected site ground conditions	1,113	0,754	3
EF7	Poor site supervision	1,245	0,751	4
EF3	Site location/environment	1,150	0,711	5
EF9	Mismanagement of resources on site	1,379	0,711	5
EF4	Lack of experience amongst workers	1,271	0,706	7
EF8	Lack of tools and equipment	1,357	0,701	8
EF10	Rework due to poor quality	1,400	0,699	9
EF6	Uncertain Ground conditions (soil type)/Uncertainty in terrain	1,213	0,685	10

SD: standard deviation; RII: relative importance index; R: rank.

5.2.5.2 Organisational/Construction firm factors

Across the endemic factors which vary from organisation to organisation, nine factors were extracted through intensive literature review and construct mapping across construction organisations. These factors are coded organisational or construction (OC) factors which range

from OC1 to OC9. Table 5.6 presents the findings of the organisational factors considered to affect the ease of digital adoption and implementation from an organisational perspective. Delays in payment of labour (RII = 0,752) is highly ranked as an impediments to technological adoption as construction organisations are generally perceived to pay both service providers and employees late; this is followed by Fluctuations in material/equipment prices (RII = 0,737); Non-payment of labour (RII = 0,728); Lack of training on new skills (RII = 0,685), and Changes in management structure (RII = 0,678). Change in government legislature/policy (RII = 0,636) is ranked the least factor across organisational and construction firms.

Table 5. 6: Impact of organisational/construction firm factors to consider in the implementation of digital technologies on construction projects.

Coding Label	Organisational/Construction firm Factors	Standard Deviation	RII	Rank (R)
OC2	Delays in payment of labour	1,394	0,752	1
OC3	Fluctuations in material/equipment prices	1,033	0,737	2
OC1	Non-payment of labour	1,453	0,728	3
OC7	Lack of training on new skills	1,393	0,685	4
OC4	Changes in management structure	1,302	0,678	5
OC5	Shortage of labour/manpower	1,412	0,676	6
OC6	Inexperienced supervisors	1,444	0,675	7
OC9	Economic changes (change in VAT, inflation and foreign exchange rates)	1,363	0,662	8
OC8	Change in government legislature/policy	1,370	0,636	9

SD: standard deviation; RII: relative importance index; R: rank.

5.2.5.3 Technical factors

Table 5.7 present the findings of technical factors (TF) considered to have a significant impact in the adoption and implementation of digital technologies, and these range from TF1 to TF11. Incomplete drawings (RII = 0,736); Change orders from the designers/consultants (RII = 0,728); poorly designed project (RII = 0,722); poor co-ordination/planning of activities (RII = 0,717), and complexity of the project (RII = 0,684) are considered to have a significant impact across the construction industry with regards to digitalising construction processes, planning the sequence or work and carrying out activities on projects. The result of the analysis further shows that Lack of Automation (robotics) (RII = 0,448) is the least ranked factor across technical factors. This thus gives the perception that it poses least threat to digitising construction processes in the South African construction industry.

Table 5. 7: Impact of technical factors to consider in the implementation of digital technologies on construction projects.

Coding Label	Technical Factors	Standard Deviation	RII	Rank (R)
TF4	Incomplete drawings.	1,349	0,736	1
TF11	Change orders from the designers/consultants.	1,227	0,728	2
TF1	Poorly designed project.	1,392	0,722	3
TF6	Poor co-ordination/planning of activities.	1,293	0,716	4
TF7	Complexity of the project.	1,361	0,684	5
TF10	Inspection delays from engineers.	1,309	0,654	6
TF3	Absence of digital collaboration amongst professionals.	1,344	0,618	7
TF5	Methods of construction (prefabrication vs onsite).	1,331	0,603	8
TF9	Buildability of the structure.	1,279	0,600	9
TF2	Lack of Digital Software.	1,316	0,591	10
TF8	Lack of Automation (robotics).	1,203	0,448	11

SD: standard deviation; RII: relative importance index; R: rank.

5.2.5.4 Overall perception of external factors and their perceived impact on the digitalisation of construction projects

Table 5.8 aggregates the perception of external factors to elucidate significance across environmental, organisational/construction firm and technical factors most significant. The ranking shifts ever so slightly across factors that have a significant impact on the adoption and implementation of digital technologies.

Table 5. 8: Impact of technical factors to consider in the implementation of digital technologies on construction projects.

Coding Label	Environmental Factors	SD	RII	Rank	ØRII	OR
E1	Inclement weather (rain/cold/heat)	1,054	0,811	1	0,729	1
E2	Unexpected site ground conditions	1,113	0,754	3		4
E3	Site location/environment	1,150	0,711	5		6
E4	Lack of experience amongst workers	1,271	0,706	7		8
E5	Delays in delivery of material	1,162	0,757	2		3
E6	Uncertain Ground conditions (soil type)/Uncertainty in terrain	1,213	0,685	10		17
E7	Poor site supervision	1,245	0,751	4		2
E8	Lack of tools and equipment	1,357	0,701	8		13
E9	Mismanagement of resources on site	1,379	0,711	5		6
E10	Rework due to poor quality	1,400	0,699	9		15
OC1	Non-payment of labour	1,453	0,728	3	0,692	10
OC2	Delays in payment of labour	1,394	0,752	1		5
OC3	Fluctuations in material/equipment prices	1,033	0,737	2		8
OC4	Changes in management structure	1,302	0,678	5		19
OC5	Shortage of labour/manpower	1,412	0,676	6		23

OC6	Inexperienced supervisors	1,444	0,675	7		20
OC7	Lack of training on new skills	1,393	0,685	4		20
OC8	Change in government legislature/policy	1,370	0,636	9		25
OC9	Economic changes (change in VAT, inflation and foreign exchange rates)	1,363	0,662	8		22
T1	Poorly designed project	1,392	0,722	3	0,646	13
T2	Lack of Digital Software	1,316	0,591	10		29
T3	Absence of digital collaboration amongst professionals	1,344	0,618	7		26
T4	Incomplete drawings	1,349	0,736	1		12
T5	Methods of construction (prefabrication vs onsite)	1,331	0,603	8		27
T6	Poor co-ordination/planning of activities	1,293	0,716	4		16
T7	Complexity of the project	1,361	0,684	5		18
T8	Lack of Automation (robotics)	1,203	0,448	11		30
T9	Buildability of the structure	1,279	0,600	9		28
T10	Inspection delays from engineers	1,309	0,654	6		24
T11	Change orders from the designers/consultants	1,227	0,728	2		10

SD: standard deviation; RII: relative importance index; ØRII: average relative importance index; R: rank; OR: overall rank

5.2.6 Determinants of construction productivity

A significant point of contention within the construction industry is the absence of standardised methodologies and formulae for measuring project productivity. Table 5.9 presents the analysis of how project productivity is measured or ascertained across construction projects in South Africa. As can be seen in Table 5.9, meeting the client's requirements/satisfaction (RII = 0,865) is perceived to be a significant indicator of optimal project productivity; this is followed by quality – intended utility of the project (RII = 0,859); adherence to health and safety – no fatalities (RII = 0,856); completing the project within time (RII = 0,789) and completing the project within cost (RII = 0,766). However, one of the methods of analysis considered to be the least effective quantifier, is decreased dependence on external resources – optimisation of resources. (RII = 0,668). The development of new technological capacity (RII = 0,662) is the least used measure for productivity determination on construction projects.

Table 5. 9: Determinants and quantifiers of construction project productivity.

Coding Label	Measurement of Productivity on projects.	Standard Deviation	RII	Rank (R)
PSM3	Meeting the client's requirements/satisfaction.	0,907	0,865	1
PSM7	Quality – Intended utility of the project.	0,962	0,859	2
PSM6	Adherence to health and safety – No fatalities.	1,058	0,856	3
PSM2	Completing the project within time.	1,068	0,789	4
PSM1	Completing the project within cost.	1,146	0,766	5

PSM10	Increased organisational reputation.	1,134	0,766	5
PSM12	Ability to mitigate external and internal forces on the project.	1,149	0,744	7
PSM4	Total Factor Productivity (TFP).	1,126	0,741	8
PSM11	Labourer's satisfaction during the development.	1,180	0,735	9
PSM5	Average Factor Productivity (AFP).	1,065	0,687	10
PSM9	Decreased Dependence on external resources – optimisation of resources.	1,276	0,668	11
PSM8	Development of new Technological capability.	1,249	0,662	12

SD: standard deviation; RII: relative importance index; R: rank.

5.2.7 Digitalisation enablers

In order to determine the extent of investment required from organisations, government, and stakeholders within the construction industry, it is essential to first examine the perceived measures that function as enablers in this endeavour. Table 5.10 shows that the perception amongst the research respondents, Upskilling/training of construction personnel (RII = 0, 803) is a significant enabler to the adoption of digital tools; followed by Collaborative relations across professionals (RII = 0,790); Investment by companies into new digital technologies and software (RII = 0,787); Adopt construction waste management (Lean construction) (RII = 0,755) and Inability of the construction industry to adapt to new technologies and new methods of construction – risk averse (RII = 0,748). However, the analysis does evidence that for the South African construction industry, Automation (utilisation of robotics) (RII = 0,597) is the least significant enabler to digitising the construction industry in South Africa. This is attributed to the capacity and pace of adoption in the South African construction industry (van Wyk *et al.*, 2024a).

Table 5. 10: Digital technology enablers in the construction industry.

Coding Label	Measurement of Productivity on projects.	Standard Deviation	RII	Rank (R)
EN6	Upskilling/training of construction personnel.	1,133	0,803	1
EN3	Collaborative relations across professionals.	0,974	0,790	2
EN5	Investment by companies into new digital technologies and software.	1,061	0,787	3
EN4	Adopt construction waste management (Lean construction).	1,015	0,755	4
EN8	Inability of the construction industry to adapt to new technologies and new methods of construction – risk averse.	1,214	0,748	5
EN7	Construction specialised entrepreneurship.	1,131	0,740	6
EN2	Construction professionals to operate with legislature fostering use of digital tools (through design to construction phase).	1,180	0,730	7
EN1	Amend the JBCC/FIDIC to enforce digitalisation to be an integral of public and private contracts tendering process.	1,328	0,717	8
EN9	Automation (utilisation of robotics).	1,184	0,597	9

SD: standard deviation; RII: relative importance index; R: rank.

5.2.8 Digitalisation barriers

A comprehensive examination of the variables that influence and impede digitisation within the construction industry is essential. Table 5.11 presents a summary of the analysis, illustrating the dynamics that hinder the adoption and implementation of digital tools across the South African construction industry. Resources to pay for digital technologies (software for a digital environment) (RII = 0,731) was the most significant dynamic that hinders digital adoption. This was followed by no training and knowledge of digital technologies (RII = 0,724), and the expense and cumulative operation costs to the organisation (RII = 0,724) as equally significant. This was followed by; lack of investment in the use of digital technologies by both government and private sector (RII = 0,731). However, the two least ranked impediments to digitising were fragmentation of the construction process (RII = 0,663) and aversion of stakeholders (RII = 0,663).

Table 5. 11: Digital technology barriers in the construction industry.

Coding Label	Identified Barrier	Standard Deviation	RII	Rank (R)
BR4	Resources to pay for digital technologies (software for a digital environment).	1,198	0,731	1
BR2	No training and knowledge of digital technologies.	1,197	0,724	2
BR9	The expense and cumulative operation costs to the organisation.	1,263	0,724	2
BR6	Lack of investment in the use of digital technologies by both government and private sector.	1,220	0,713	4
BR8	Lack of Technical abilities to operate digital technologies (software).	1,258	0,713	4
BR7	Complexity of the construction project.	1,175	0,692	6
BR1	The lack of skills across professionals.	1,331	0,684	7
BR3	Fragmentation of the construction process.	1,283	0,663	8
BR5	Aversion of stakeholders.	1,153	0,663	8

SD: standard deviation; RII: relative importance index; R: rank.

5.2.9 Proficiency of digital tools utility across professional team during the planning phase of a development

The study aimed to assess the efficacy and expected proficiency of digitalising the construction process. This was divided into three categories namely, the planning, design and construction phase. The aim of this inquisition was to evaluate the expected level understanding, knowledge and comfortability of the various professional teams. Table 5.12 reports on the stakeholders which are expected to be significantly knowledgeable and well acquainted of digital tools

across the planning stage of a development. Project manager (PM) (RII = 0,833) must have a significant comprehension of the application of digitalization; followed by civil engineer/structural engineer (RII = 0,825) and principal agent (RII = 0,811). During the planning stage of a development, mechanical engineer (RII = 0,730) least required member of the professional team to be adept with digitalization.

Table 5. 12: Proficiency in the use of digital technologies during the planning phase of a development.

Skill, knowledge and experience proficiency in the utilisation of digital technologies during the Planning stage across professional team.	Standard Deviation	RII	Rank (R)
Project Manager (PM)	1,088	0,833	1
Civil Engineer/Structural Engineer	1,079	0,825	2
Principal Agent	1,202	0,811	3
Costing Engineer/Manager	1,188	0,808	4
Quantity Surveyor (QS)	1,206	0,786	5
Construction Manager (CM)	1,228	0,784	6
Client	1,214	0,751	7
Architect	1,398	0,735	8
Mechanical Engineer	1,348	0,730	9

SD: standard deviation; RII: relative importance index; R: rank.

5.2.10 Proficiency of digital tools utility across professional team during the design phase of a development

The design stage incorporates a significant contribution of the various professional team members and as a result, the inquisition to the proficiency of digital adeptness was imperative. Table 5.13 reports that Principal Agent (RII = 0,831) is significantly expected to be adept with digitalisation and the various tool to be implemented. This was followed by; Project Manager (PM) (RII = 0,822); Civil Engineer/Structural Engineer (RII = 0,803) and construction manager (CM) (RII = 0,800). However, similarly to the planning stage in Table 5, 12, mechanical engineer (RII = 0,731) was least ranked.

Table 5. 13: Proficiency in the use of digital technologies during the design phase of a development.

Skill, knowledge and experience proficiency in the utilisation of digital technologies during the design stage across the professional team.	Standard Deviation	RII	Rank (R)
Principal Agent	1,030	0,831	1
Project Manager (PM)	1,021	0,822	2
Civil Engineer/Structural Engineer	1,035	0,803	3
Construction Manager (CM)	1,115	0,800	4

Costing Engineer/Manager	1,223	0,786	5
Quantity Surveyor (QS)	1,198	0,770	6
Architect	1,365	0,750	7
Client	1,164	0,736	8
Mechanical Engineer	1,328	0,731	9

SD: standard deviation; RII: relative importance index; R: rank.

5.2.11 Proficiency of digital tools utility across professional team building/construction phase of a development

There is a significant difference in the level and complexity of digital skills required during the construction phase compared with those required during the design stage of a project. Table 5.14 reports that project manager (PM) (RII = 0,859) has the most impact on the constructability of a project in digitalising the project. This is followed by construction manager (CM) (RII = 0,841); principal agent (RII = 0,826). Mechanical engineer (RII = 0,777) and architect (RII = 0,757) are least expected to have no impact on the project during the construction phase in the event that a construction project has commenced and adopted a system of digital innovation.

Table 5. 14: Proficiency in the use of digital technologies during the building/construction phase of a development.

Skill, knowledge and experience proficiency in the utilisation of digital technologies during the building/construction phase across the professional team.	Standard Deviation	RII	Rank (R)
Project Manager (PM)	0,961	0,859	1
Construction Manager (CM)	1,040	0,841	2
Principal Agent	1,128	0,826	3
Civil Engineer/Structural Engineer	1,004	0,817	4
Costing Engineer/Manager	1,167	0,806	5
Quantity Surveyor (QS)	1,124	0,797	6
Client	1,075	0,784	7
Mechanical Engineer	1,222	0,777	8
Architect	1,293	0,757	9

SD: standard deviation; RII: relative importance index; R: rank.

5.3 Influence of digitalisation on productivity

Table 5.15 presents the findings of the perceptions of how significantly digitalising the construction industry influence productivity. This presentation is assessed across the identified constructs synthesised from intensive literature review. These are coded improvement

measures (IM) and they range from IM1 to IM9. Efficient communication (RII = 0,822) was ranked atop the influences of digitalising the construction process. This was followed by; allows for quick information transfer (RII = 0,804); improved project performance (RII = 0,783); information transparency amongst the professional team (RII = 0, 776); and improves construction productivity on-site (RII = 0,730). Across the impacts analysed, decreases the construction period (RII = 0,652) was ranked the least impact of digitalising the construction project process.

Table 5. 15: The impacts of digitalisation on the construction development and project performance.

Coding Label	Impacts of digitalisation on project scope	Standard Deviation	Mean	MIS	Rank (R)
IM8	Efficient communication	1,104	4,110	0,822	1
IM7	Allows for quick information transfer	1,099	4,020	0,804	2
IM9	Improved project Performance	1,173	3,910	0,783	3
IM3	Information transparency amongst the professional team	1,128	3,880	0,776	4
IM2	Improves construction productivity on-site	1,199	3,650	0,730	5
IM6	Improves the quality of the development (building)	1,217	3,650	0,730	5
IM4	Risk reduction due to shared digital resources	1,081	3,590	0,717	7
IM1	Minimises design costs	1,264	3,300	0,661	8
IM5	Decreases the construction period	1,291	3,260	0,652	9

SD: standard deviation; RII: relative importance index; R: rank.

5.4 Data Analysis (Partial Least Squares Structural Equation Modelling) PLS-SEM

In reviewing the hypotheses, it is essential to distinguish between the different statistical analysis techniques employed in their evaluation. For the qualitative component of the research, the three main data analysis tools used were partial least squares structural equation modelling (PLS-SEM 4). PLS-SEM 4 was employed due to its capability to perform robust analyses when evaluating and testing a hypothesis anchored on a theoretical framework, which is the foundation of this study (Hair *et al.*, 2019; Purwanto and Sudargini, 2021; Usakli and Rasoolimanesh, 2023). Additionally, this model is utilised due to its complexity and ease of assessment across many constructs involved in the study. Another data analysis tool used is IBM SPSS. This software comprises a combination of limitless methods of data analysis functionality which is fitting to both nonparametric and normally distributed data sets (Mallery and George, 2005). Lastly, another tool used to analyse data was Microsoft Excel, particularly in the presentation, validating standard deviations, RII, MIS and ranking constructs.

The study posits three hypotheses to be tested. The selected techniques used to test the study hypotheses are underpinned by the nonparametric nature of the distribution of quantitative data. As a result, analytical techniques that most effectively distil information and provide robust, scientifically rigorous, and reliable analyses are presented. In lieu of the complexity and large number of study constructs, the hypotheses are answered with the variable codes. The three research hypotheses are stated and tested in the following sections.

5.4.1 Testing for Hypothesis One

H1 (Null): There is no significant relationship between digitalisation techniques (innovative technology) and the level of construction productivity on projects.

H1: There is a significant relationship between digitalisation techniques (innovative technology) and the level of construction productivity on projects.

As stated in Chapter 3, reliability refers to the consistency of the data and validity refers to the accuracy of data (Taber, 2018). In ensuring construct reliability and validity, the study ensured that Cronbach's alpha is calculated for the constructs before the analysis was conducted. As can be seen in Table 5.17 the desired computation of Cronbach's alpha has to be is greater than 0,70. For this analysis, the observed Cronbach's alpha value was 0,952 which shows that the internal items are related perfectly to each other. As a result, this shows that the scale utilised is reliable for use and thus an analysis can be conducted. Furthermore, the calculation of the Average Variance Extracted (AVE) is essential when using PLS-SEM for analysis, as it ensures convergent validity by indicating the extent to which each construct explains the variance in its observed indicators. According to (Hair *et al.*, 2019), a value exceeding 0,500 is the desired indicator of validity. For this study, it can be seen in the computations presented in Table 5.17 that the AVE value of 0,667 was achieved, thus ascertaining convergent validity.

Figure 5.2 and Figure 5.3 presents PLS-SEM analysis results. The analysis in Figure 5.2 reveals that a path coefficient of 0.673 is observed between Digital technologies and Productivity, which indicates a strong positive statistically significant relationship. Furthermore, Table 5.16 indicates that a p-value of 0.000 is achieved which according to Hair *et al.* (2019) and Usakli and Rasoolimanesh (2023), at a confidence interval of 95% a p-value below 0,05 is statistically significant thus indicating the significance of this study's significance. This is the case in this first iteration of the analysis, and the observed p-value is below the 0.05 significance threshold.

This thus confirms that the relationship between digital technologies and productivity is statistically significant. Table 5.17 presented the finding of the R and R-adjusted values, and these are recorded as R^2 being 0,472 and the adjusted R^2 value being 0,467. It can thus be deduced that these findings refute H1 (Null) and accepts H1 as evidenced by the statistically significant relationship observed.

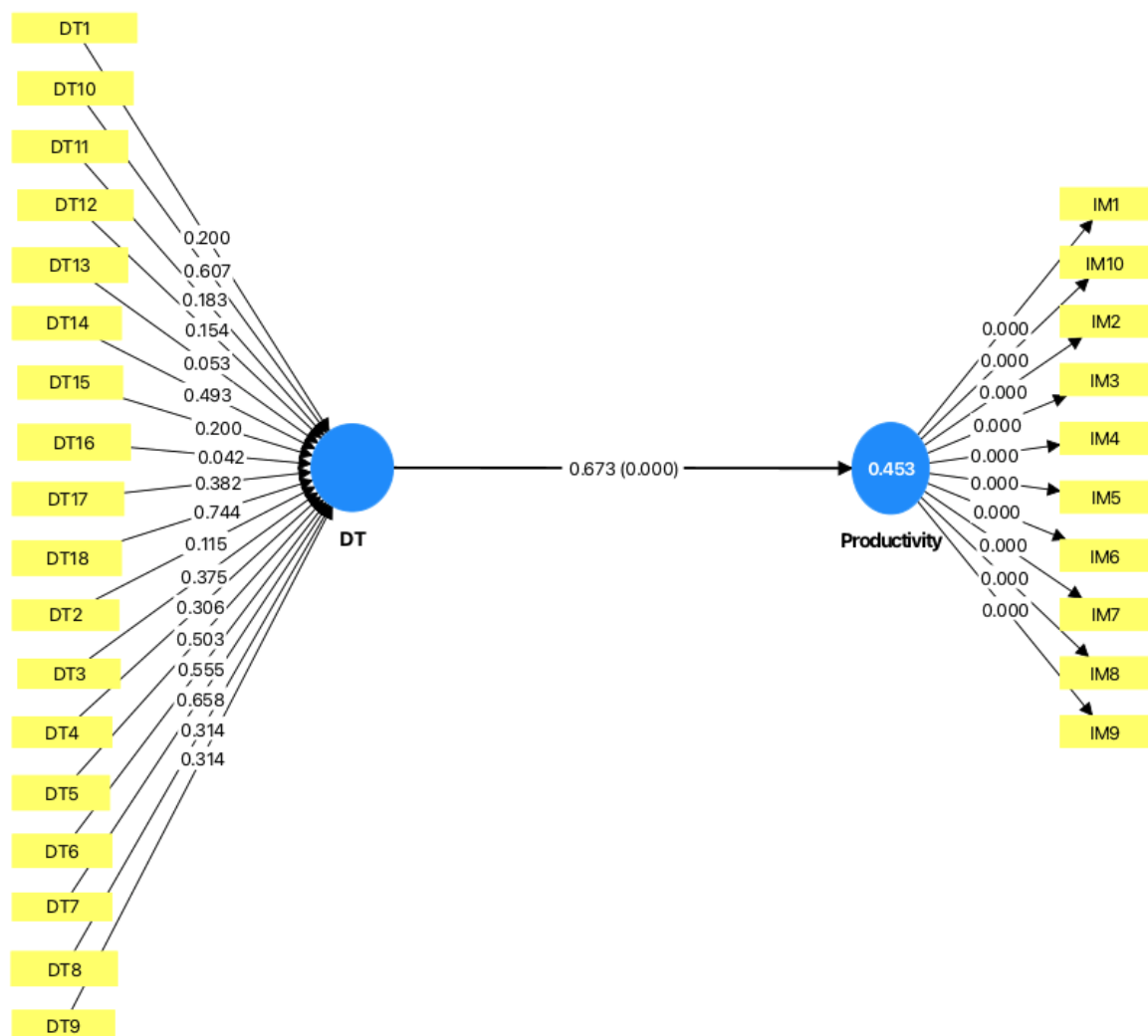


Figure 5. 2: PLS-SEM Hypothesis I Test (Digital Technologies and Productivity).

However, further interrogation of the analysed data presents the variance inflation factor (VIF), which according to Hair et al. (2019), assesses multicollinearity which occurs across constructs. The objective of VIF is to evaluate the degree of multicollinearity among predictor variables by quantifying how strongly each variable is linearly related to the others in the model, despite

their assumed independence in the analysis. A strong or high correlation across constructs significantly affects the uniqueness of how constructs affect the dependent variable (productivity). This effect is said to distort and bring into question the true direction of the path coefficient and subsequently inflate the standard errors in the construct set. However, Hair et al. (2019) and Paulmakesh and Makebo (2022) asserts that for a p-value to reflect the true relationship between the constructs and their relation to the effect on the dependent factor, as well as for the R-square to hold rigour and deviate from inflationary perceptions, the VIF values which should be acceptable should be closer to 3 (Purwanto and Sudargini, 2021). Notwithstanding that, VIF values that range between 3 and 5 is accepted.

Table 5.18 reports VIF values observed and as can be seen, all the construct values observed fall below 5 with the exception of DT7 (VIF = 5,907), IM9 (VIF = 12,171) and IM10 (VIF = 8,763). This observation indicates that the research constructs in this model are closely correlated and positively affect the reliability of the path coefficients (Purwanto and Sudargini, 2021). This implies that DT7 (Digital Twins), IM9 (improved project performance) and IM10 (enhancing safety – quick detection), have the potential to discredit the model's rigour and dependence with this statistically significant multicollinearity. Notwithstanding that, across other variables that affect productivity, these are the least and insignificant. Included in Table 5.18 is the results presenting another iteration of the model which shows new VIF (Model Adjusted) values. As Figure 5.2 represents a model with the inclusion of all constructs, Figure 5.3 represents an iteration (structural model) of the model with the exclusion of these DT7, IM9 and IM10 in the computation of the new path coefficient. As can be seen in Figure 5.3 the new observed path coefficient of 0,646 is observed which is also statistically significant. Table 5.19 presents the analysis of the effect digital technologies assessed impact productivity observed. This indicates that there is a strong relationship between the two variables as evidenced by a p value of 0,046. In addition, this is further corroborated by the new observed p-value of 0,000 which signifies a statistically significant relationship which further confirms the acceptance of H1.

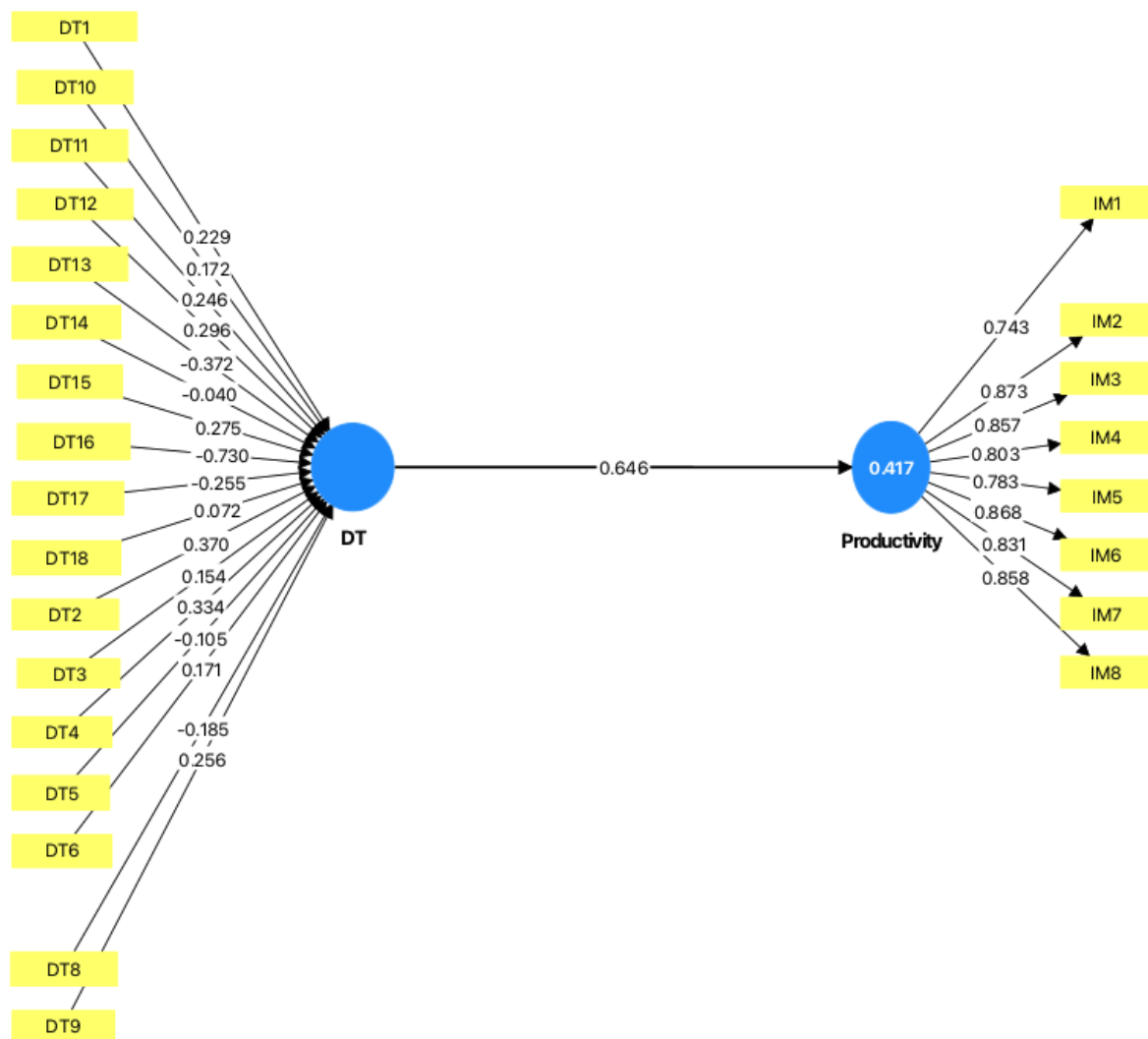


Figure 5. 3: PLS-SEM Hypothesis I Test (Digital Technologies and Digital Technologies and Productivity – Adjusted model).

Table 5. 16: PLS-SEM – p values for digital technologies and impact on levels of project productivity.

	Original Sample (O)	Sample Mean (M)	STDEV	T Statistic	P value
DT->Productivity	0,687	0,764	0,044	15,55	0,000

Table 5. 17: PLS-SEM Construct reliability and validity of Digital Technologies and Digital Technologies and Productivity

	Cronbach's alpha	Composite reliability (rho a)	Composite reliability (rho c)	Average Variable Expected (AVE)	R-square	R-square adjusted
DT->Productivity	0,952	0,959	0,952	0,667	0,472	0,467

Table 5. 18: Collinearity statistics -Variable Inflation Factor (VIF) for digital technologies and impact on project productivity.

Collinearity statistics (VIF) - Outer model - list	VIF	VIF (Model Adjusted)
DT1	3.262	3.221
DT10	2.236	2.232
DT11	3.056	3.005
DT12	2.663	2.640
DT13	1.825	1.815
DT14	3.247	3.243
DT15	2.541	2.247
DT16	4.863	4.217
DT17	3.480	3.465
DT18	3.085	2.928
DT2	4.913	4.170
DT3	3.001	2.876
DT4	4.260	4.213
DT5	4.278	4.029
DT6	2.103	1.804
DT7	5.907	-
DT8	3.046	2.620
DT9	3.171	2.996
IM1	2.055	2.046
IM10	8.763	-
IM2	3.871	3.680
IM3	3.977	3.892
IM4	2.312	2.281
IM5	2.518	2.460
IM6	4.037	3.712
IM7	3.007	3.015
IM8	4.854	4.354
IM9	12.171	-

Table 5. 19: F-square matrix for digital technologies and impact on project productivity.

	Original Sample (O)	Sample Mean (M)	STDEV	T Statistic	P value
DT->Productivity	0,895	1,484	0,449	1,994	0,046

5.4.2 Testing for Hypothesis two

H2 (Null): There is no significant relationship between external factors (environmental, organisational/firm, technical) and adoption-willingness for construction organisations to implement digital technologies.

H2: There is a significant relationship between external factors (environmental, organisational/firm, technical) and adoption-willingness for construction organisations to implement digital technologies.

In a manner consistent with Hypothesis One, the validity and reliability of the constructs associated with Hypothesis Two were assessed. Table 5.20 presented the Cronbach's alpha for variables used in evaluating the relationship between productivity and environmental factors. As can be seen, the observed value is 0,883 which is above 0,70 thus expressing a strong internal items relatability. Furthermore, the observed Cronbach's alpha observed for organisational/firm factors is 0,90 and presented in Table 5.21. And lastly, a Cronbach's alpha of 0,952 was observed for technical factors which is presented in Table 5.22. This validates that the measured constructs are related to each other across the three sub-categories expressed in Tables 5.20 to Table 5.22, and thus valid for the analysis in this study (Hair *et al.*, 2019). It must be noted that in so much as the reliability is ascertained for the constructs, assessing the AVE for both environmental and organisational/Firm factors is imperative as they both fall below the 0,500 threshold as stipulated by Hair *et al.* (2019). A further assessment of this variance is necessary in order to maintain validity of findings. Moreover, it can further be observed in Figure 5.4, Figure 5.5 and Figure 5.6 that there is good model fit for these constructs, as a result they are retained (Usakli and Rasoolimanesh, 2023).

Table 5. 20: Construct Reliability and Validity – Environmental factors and Productivity.

	Cronbach's alpha	Composite reliability (rho a)	Composite reliability (rho c)	Average Variable Expected (AVE)
DT	0,950	0,960	0,955	0,543
Environmental Factors	0,883	0,021	0,702	0,223
Productivity	0,945	0,950	0,954	0,696

Table 5. 21: Construct Reliability and Validity – Organisational/Firm factors and Productivity.

	Cronbach's alpha	Composite reliability (rho a)	Composite reliability (rho c)	Average Variable Expected (AVE)
DT	0,950	0,960	0,955	0,543
Organisatiobal_Factors	0,903	0,560	0,887	0,470
Productivity	0,952	0,960	0,959	0,700

Table 5. 22: Construct Reliability and Validity – Technical factors and Productivity.

	Cronbach's alpha	Composite reliability (rho a)	Composite reliability (rho c)	Average Variable Expected (AVE)
DT	0,950	0,960	0,955	0,544
Technical Factors	0,952	0,965	0,959	0,700
Productivity	0,951	0,855	0,951	0,641

5.4.2.1 Environmental Factors

Hypothesis 2 interrogates external factors clustered across their significant categorisations which are Environmental factors, Organisational/Firm factors, as well as Technical factors. These are tested against digital technologies as a moderator to how they impact project productivity. Figure 5.4 to Figure 5.6 represents a depiction of how these categories impact project productivity and the respective path coefficients and p-values are discussed.

In analysing the relationship across Environmental factors and Productivity when mediated by digital tools, the PLS-SEM structural equation modelling analysis indicated a path coefficient of -0,159. However, the strength and significance of this coefficient is considered to have a moderately strong inverse relationship on productivity. Furthermore, the p-value observed was 0,195 which falls above the 0.05 threshold. The p-value demonstrates that this relationship is statistically not significant. Following which, the model reported an adjusted R^2 value of 0,467. This relationship corroborates the relationship observed in Figure 5.4. In the analysis of the AVE observed, Table 5.20 shows that the Environmental_Factors presented a value of 0,223 which falls below 0,500 threshold and thus invalidating the constructs. However, all the VIF values falls within the parameters stipulated for validity (Hair *et al.*, 2019). The assessment of VIF across DTs and Productivity ($VIF = 1.204$), Environmental_Factors and Productivity ($VIF = 1.050$) and that which is moderated by DTs between Environmental_Factors and Productivity (DTxEnvironmental_Factors and Productivity) is 1,214. And all these. The results indicated that all predictor variables exhibited variance inflation factor (VIF) values below the recommended threshold of 3, suggesting that multicollinearity was not a concern. This further purport the fact that a negligible multicollinearity exists across these constructs, confirming that the structural model estimates are not biased with regards to collinearity. As a result, rigour and independence are maintained. Table 5.24 provides the presentation of these results. However, since this Hypothesis analyses external factors, it is imperative to magnify the analysis on the outcomes of the other two categories of external factors.

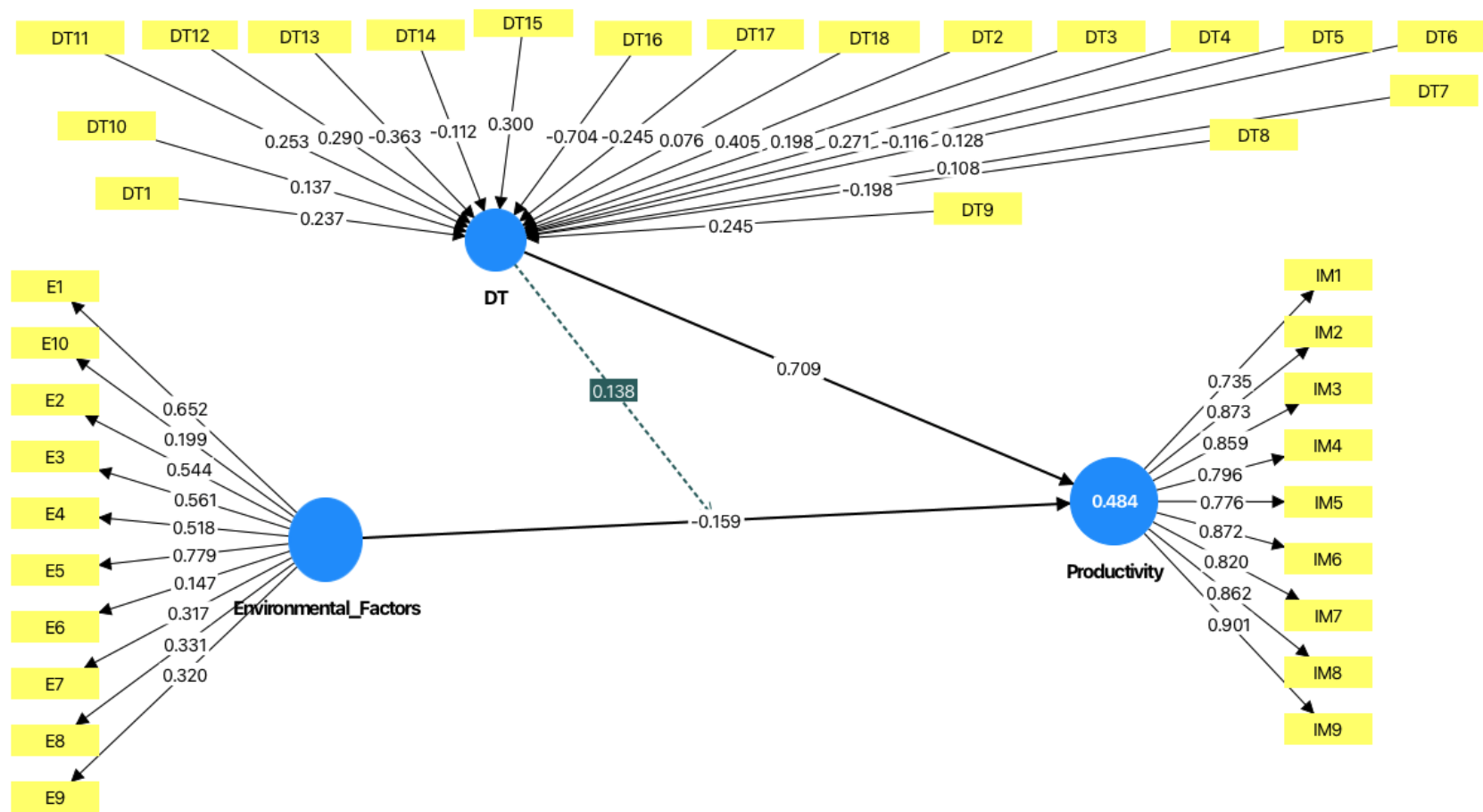


Figure 5. 4: PLS-SEM Hypothesis 2 Test (Digital Technologies as a mediator – Environmental Factors and impact on Productivity).

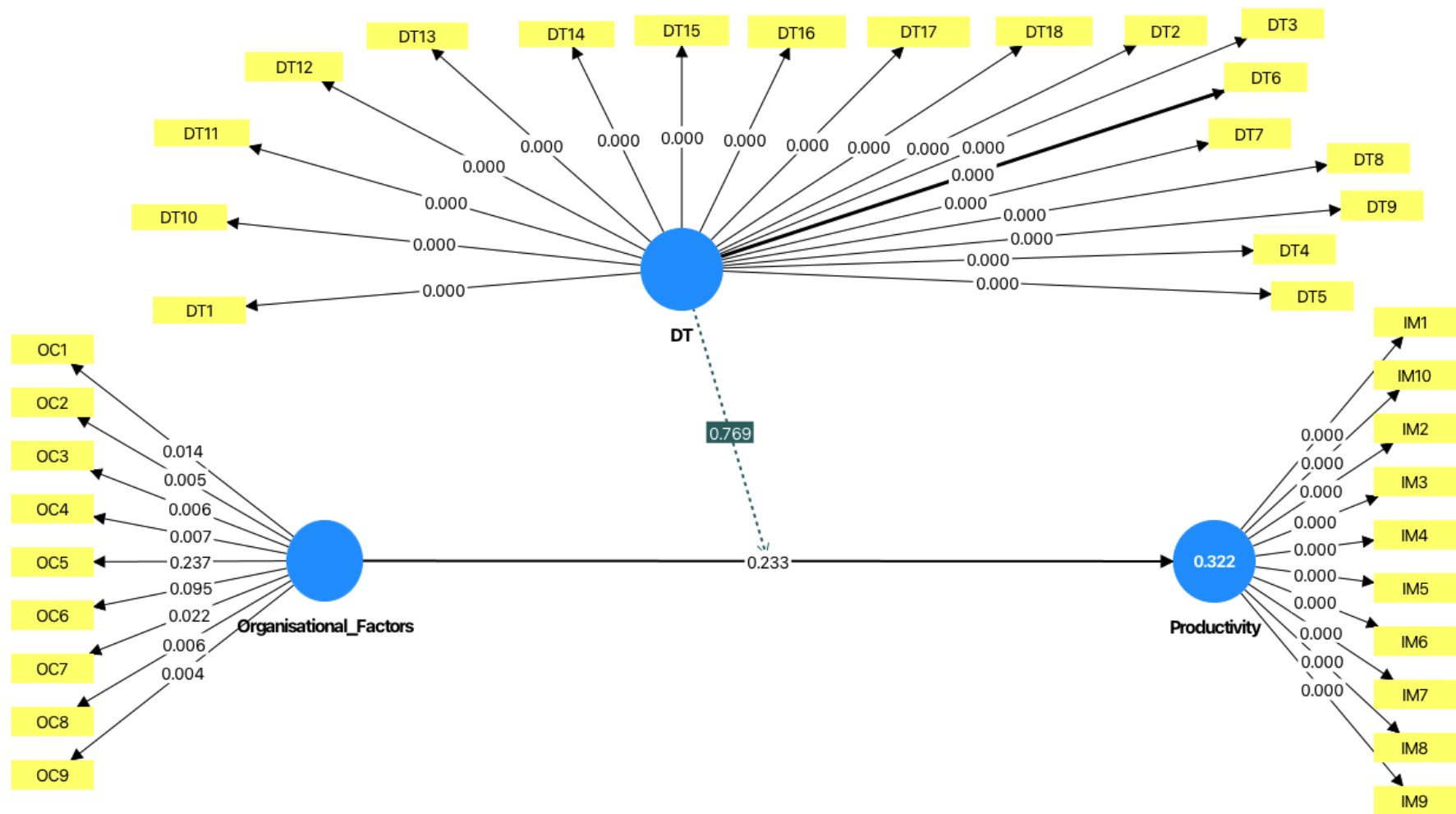


Figure 5. 5: PLS-SEM Hypothesis 2 Test (Digital Technologies as a mediator – Organisational/Firm Factors and impact on Productivity).

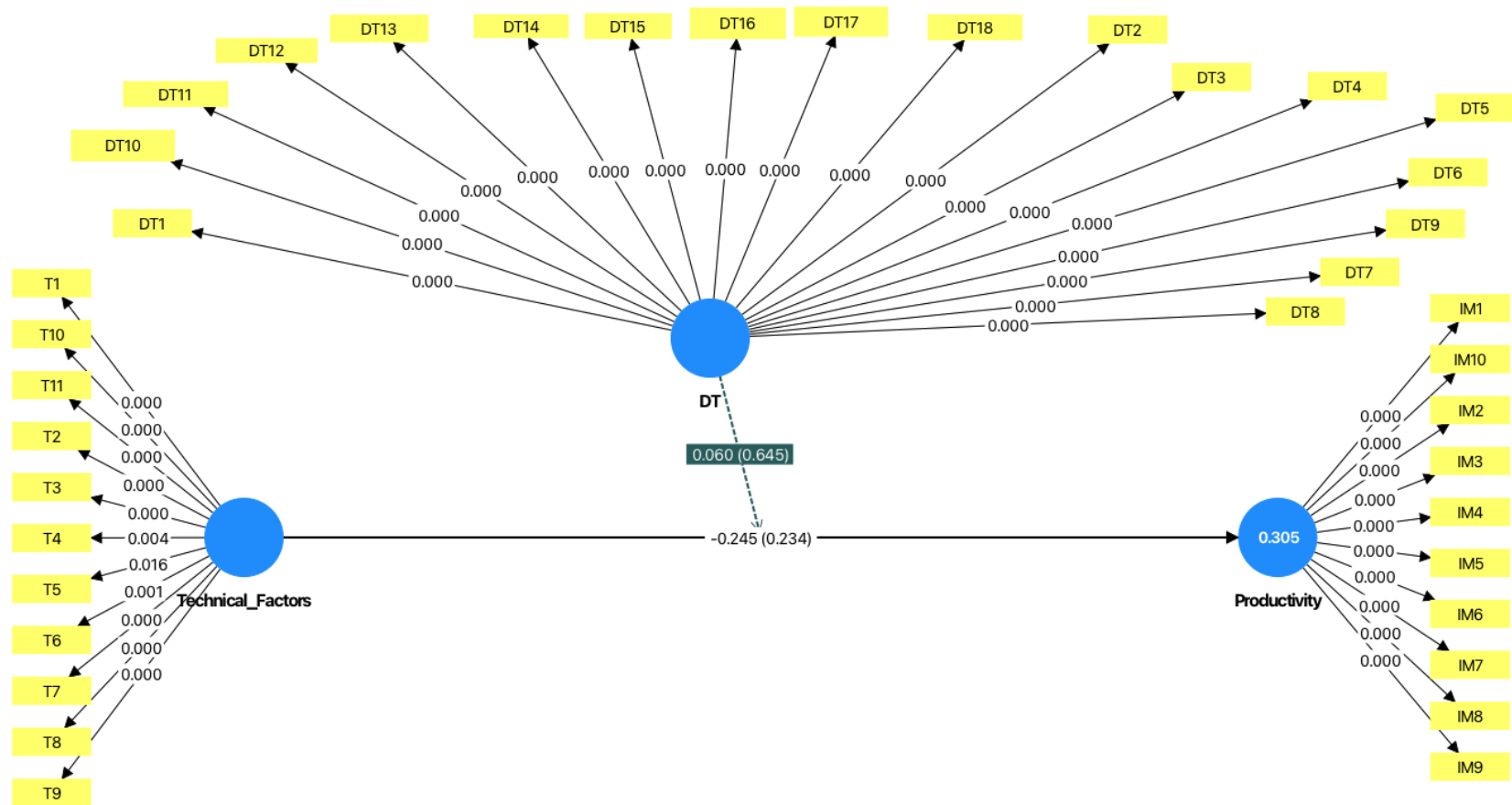


Figure 5. 6: PLS-SEM Hypothesis 2 Test (Digital Technologies as a mediator – Technical Factors and impact on Productivity)

Table 5. 23: PLS-SEM – p values for Digital Technologies as a mediator – Environmental Factors and impact on Productivity.

	Original Sample (O)	Sample Mean (M)	STDEV	T Statistic	P value
DT->Productivity	0,709	0,726	0,052	13,26	0,000
DTxEnvironmental_Factors->Productivity	0,138	0,05	0,11	1,257	0,209
Environmental_Factors->Productivity	-0,159	-0,077	0,123	1,297	0,195

Furthermore, Table 5.25 reports the f^2 results of the interconnectedness and complex model depiction of environmental factors. The value of 0,224 was observed which signifies a moderately statistically significant relationship between environmental factors constructs and Productivity (Paulmakesh and Makebo, 2022).

Table 5. 24: Collinearity statistics -Variable Inflation Factor (VIF) for Digital Technologies as a mediator – Environmental Factors and impact on Productivity.

	DT	Environmental_Factors	Productivity	DTxEnvironmental_Factors
DT			1,204	
Environmental_Factors			1,05	
Productivity				
DTxEnvironmental_Factors			1,214	

Table 5. 25: F-square matrix for Digital Technologies as a mediator – Environmental Factors and impact on Productivity.

	Original Sample (O)	Sample Mean (M)	STDEV	T Statistic	P value
DT->Productivity	0,81	1,161	0,348	2,325	0,020
DTxEnvironmental_Factors->Productivity	0,056	0,047	0,046	1,216	0,224
Environmental_Factors->Productivity	0,047	0,047	0,047	0,991	0,322

Table 5. 26: Discriminant validity – Fornell-Larcker criterion for Digital Technologies as a mediator – Environmental Factors and impact on Productivity.

	Environmental_Factors	Productivity	DTxEnvironmental_Factors
Environmental_Factors			
Productivity	0,137		
DTxEnvironmental_Factors	0,132	0,133	

5.4.2.2 Organisational/Firm Factors

The analysis of the relationship across Organisational/Firm factors and Productivity when moderated by Digital tools revealed the following results through PLS-SEM structural equation modelling. A path coefficient of -0,276 with a p-value of 0,233 which does not follow the

convention of a threshold below 0.05. The p-value demonstrates that this relationship is statistically not significant. Following which, the model reported an adjusted R² value of 0,299. The analysis of AVE is presented in Table 5.21. The assessment of VIF values is presented in Table 5.28. The presented VIF across DTs and Productivity (VIF = 1.020), Organisational/Firm_Factors and Productivity (VIF = 1, 061) and that which is moderated by DTs between Organisational/Firm _Factors and Productivity (DTxOrganisational/Firm _Factors and Productivity) the VIF value is 1,076. This indicated that all predictor variables had VIF values below the recommended threshold of 3. This confirms that the structural model estimates are not biased by collinearity.

Table 5. 27: PLS-SEM – p values for Organisational/firm factors with digitalisation as a moderator to impacting productivity.

	Original Sample (O)	Sample Mean (M)	STDEV	T Statistic	P value
DT->Productivity	0,671	0,703	0,057	11,856	0,000
DTxOrganisational/Firm_Factors->Productivity	0,091	0,072	0,100	0,917	0,359
Organisational/Firm_Factors->Productivity	-0,209	-0,117	0,147	1,424	0,154

Table 5.29 reports that the f² results of the interconnectedness and complex model depiction of organisational/firm factors was observed to be 0,004 which denotes that there is no statistically significant relationship between environmental factors constructs and Productivity.

Table 5. 28: Collinearity statistics -Variable Inflation Factor (VIF) for Organisational/firm factors with digitalisation as a moderator to impacting productivity

	DT	Organisational/Firm_Factors	Productivity	DTxOrganisational/Firm_Factors
DT			1,020	
Organisational/Firm_Factors			1,061	
Productivity				
DTxOrganisational/Firm_Factors			1,076	

Table 5. 29: F-square matrix for Organisational/firm factors with digitalisation as a moderator to impacting productivity.

	DT	Organisational/Firm_Factors	Productivity	DTxOrganisational/Firm_Factors
DT			0,379	
Organisational/Firm_Factors			0,110	
Productivity				
DTxOrganisational/Firm_Factors			0,004	

Table 5. 30: Discriminant validity – Fornell-Larcker criterion for Organisational/firm factors with digitalisation as a moderator to impacting productivity.

	DT	Organisational/Firm_Factors	Productivity	DTxOrganisational/Firm_Factors
DT				
Organisational/Firm_Factors	0,204			
Productivity	0,472	0,186		
DTxOrganisational/Firm_Factors	0,107	0,223	0,060	

5.4.2.3 Technical Factors

Lastly, the analysis of the relationship across technical factors and productivity when moderated by digital tools revealed the following results through PLS-SEM structural equation modelling. A path coefficient of -0,245 with a p-value of 0,234 which does not follow the convention of a threshold below 0.05. The p-value demonstrates that this relationship is statistically not significant. Following which the model reported an adjusted R² value of 0,281. The analysis of AVE is presented in Table 5.22. The assessment of VIF is presented in Table 5.32. The presented VIF across DTs and Productivity (VIF = 1,042), Technical_Factors and Productivity (VIF = 1, 175) and that which is moderated by DTs between Technical_Factors and Productivity (Technical_Factors and Productivity) the VIF value is 1,217. This indicated that all predictor variables had VIF values below the recommended threshold of 3. This confirms that the structural model estimates are not biased by collinearity.

Table 5. 31: PLS-SEM – p values for Technical factors with digitalisation as a moderator to impacting productivity.

	Original Sample (O)	Sample Mean (M)	STDEV	T Statistic	P value
DT->Productivity	0,497	0,5	0,057	8,787	0,000
DTxTechnical_Factors->Productivity	0,06	0,066	0,130	0,461	0,645
Technical_Factors->Productivity	-0,245	-0,237	0,206	1,19	0,234

Table 5. 32: Collinearity statistics -Variable Inflation Factor (VIF) for Technical factors with digitalisation as a moderator to impacting productivity.

	DT	Technical_Factors	Productivity	DTxTechnical_Factors
DT			1,042	
Technical_Factors			1,175	
Productivity				
DTxTechnical_Factors			1,217	

Table 5. 33: F-square matrix for Technical factors with digitalisation as a moderator to impacting productivity.

	DT	Technical_Factors	Productivity	DTxTechnical_Factors
DT			0,392	
Technical_Factors			0,102	
Productivity				
DTxTechnical_Factors			0,013	

Table 5.33 reports that the f^2 results of the interconnectedness and complex model depiction of technical factors was observed to be 0,013 which signifies a statistically non-significant relationship between technical factors constructs and Productivity.

Table 5. 34: Discriminant validity – Fornell-Larcker criterion for technical factors with digitalisation as a moderator to impacting productivity.

	DT	Productivity	Technical_Factors	DTxTechnical_Factors
DT				
Technical_Factors	0,179	0,209		
Productivity	0,472			
DTxTechnical_Factors	0,184	0,111	0,349	

Tables 5.26 (environmental factors), Table 5.30 (organisational/firm factors), and Table 5.34 (technical factors) represent the findings of discriminant validity (Fornell-Larcker). The Fornell-Larcker criterion provides additional evidence that latent variables are meaningful and not redundant. This assessment ensures that the measured constructs are both conceptually and empirically distinct, thereby confirming that they represent separate underlying phenomena and do not exhibit substantial overlap or redundantly measure the same construct. This ensures that confidence of variables is statistically moderated for accurate observation of relationship across variable. Ab Hamid *et al.* (2017) posited that a value between 0,00 and less than 0,70 is acceptable. As can be seen in Table 5.26, Table 5.30 and Table 5.34, all the constructs are between 0,00 – 0,70. The results of these findings are discussed in Chapter 7.

5.4.3 Testing for Hypothesis three

H3 (Null): The relationship between skills (knowledge of digitalisation technology/innovative technology) and construction project productivity, is not moderated by the adoption of digitalisation technologies (innovative technologies) on projects.

H3: The relationship between skills (knowledge of digitalisation technology/innovative technology) and construction project productivity, is moderated by the adoption of digitalisation technologies (innovative technologies) on projects.

Table 5.35 shows that the statistics for the study aligned with the Cronbach's alpha and that the constructs were not closely related. This was further evidenced by the standard expectation that AVE values must not fall below 0,500.

Table 5. 35: Discriminant validity – Fornell-Larcker criterion for construction skills with digitalisation as a moderator to impacting productivity.

	Cronbach's alpha	Composite reliability (rho a)	Composite reliability (rho c)	Average Variable Expected (AVE)
DT	0,950	0,960	0,955	0,543
Productivity	0,952	0,969	0,959	0,700

Congruent to Hypothesis 1 and hypothesis 2, there is no deviation from the statistical significance between Skill_Knowledge_Experience and productivity, with an analysed p-value of 0,812 at a confidence interval of 95%. These findings indicate a statistically insignificant relationship, providing no support for Hypothesis 3. Consequently, the null hypothesis is retained. Figure 5.7 and Table 5.36 represent these results. A closer observation of the relationship when using digital technologies as a moderator, revealed the same findings of a path coefficient of -0,170 and a p-value of 0,373. These findings indicate that skills and knowledge are critical factors influencing the effective use of digital technologies in project implementation for optimal project productivity.

Notwithstanding the rejection of Hypothesis 3, a further interrogation of the constructs used in assessment is presented. Table 5.37 presents the obtained results/analysis of VIF values and as can be seen all the obtained VIF values are congruent with the assertion that a value above 0,500 evidence credibility and valid assessment of the constructs. This can be seen with 1,059 reported for Construction_Skill and productivity, 1,016 reported for DT and Productivity and lastly the VIF value of 1,053 reported for DTxConstruction_Skill and Productivity. Table 5.38 represent the results of the f^2 for the analysis and lastly, the findings for the discriminant validity results are presented in Table 5.39.

Table 5. 36: PLS-SEM – p values for digital expertise (skills and knowledge) and impact on project productivity

	Construction_Skill	DT	Productivity	DTxConstruction_Skill
Construction_Skill			0,036	
DT			0,523	
Productivity				
DTxConstruction_Skill			-0,053	

Table 5. 37: Collinearity statistics -Variable Inflation Factor (VIF) for Skills, digitalisation and project performance

	Construction_SKill	DT	Productivity	DTxConstruction_SKill
Construction_Skill			1,059	
DT			1,016	
Productivity				
DTxConstruction_Skill			1,053	

Table 5. 38: F-square matrix for skills, digitalisation and project performance

	Construction_SKill	DT	Productivity	DTxConstruction_SKill
Construction_Skill			0,001	
DT			0,338	
Productivity				
DTxConstruction_Skill			0,003	

Table 5. 39: Discriminant validity – Fornell-Larcker criterion for skills, digitalisation and project performance

	Construction_SKill	DT	Productivity	DTxConstruction_SKill
Construction_Skill				
DT	0,139			
Productivity	0,051	0,472		
DTxConstruction_Skill	0,204	0,096	0,102	

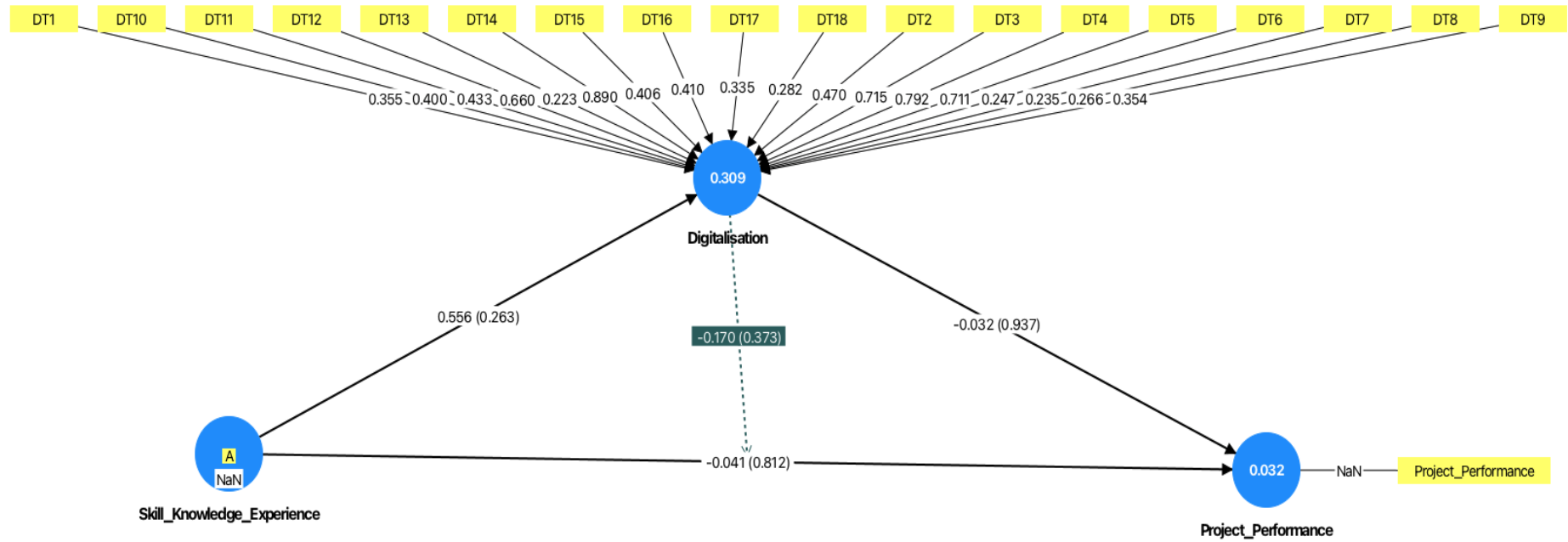


Figure 5. 7: PLS-SEM Hypothesis 3 Test (Skill_Knowledge_Experience moderated by Digital Technologies)

5.5 Validating Hypotheses (Hypothesis 1, Hypothesis 2 and Hypothesis 3) – Kruskal-Wallis and Spearman Rho analysis.

The results of the three hypotheses tests indicated both statistically significant and non-significant findings when evaluated collectively across the dependent construct. This represents an important point of departure for the interpretation of the observed relationships and correlations. However, the research found it imperative to validate these hypotheses using a different statistical analysis tool (SPSS) to validate the findings observed through PLS-SEM. This study is intended to provide a comprehensive analysis of the degree to which observed correlations align with individualistic variables (DTs), as examined across different provinces in South Africa and across various CIDB grades, segmented by specialization. The results are presented in the sections that follow.

5.5.1 Validating Hypothesis one

Hypothesis 1 of the study posits a significant relationship between digital technologies (innovative technologies) and construction productivity levels on projects. A Kruskal-Wallis hypothesis test was used to assess the correlation between the measured level of construction project productivity and the identified digital techniques. Table 5.40 presents the findings of the test. A 95% confidence level and a 5% margin of error are used. Across the eighteen identified digital technologies (DTs) (Appendix E), the test shows that DT4 ($P = 0,029$) was found to have a statistically different. Additionally, DT7 ($P = 0,041$); DT11 ($P = 0,025$) and DT12 ($P = 0,033$) all have a statistically significant difference. As a result, the null hypothesis is rejected.

Table 5. 40: Independent-Samples Kruskal-Wallis Test across South Africa.

Null Hypothesis	Test	Sig. ^{a,b}	Decision
The distribution of DT4 is the same across categories of Provinces.	Independent-Samples Kruskal-Wallis Test	0,029	Reject the null hypothesis.
The distribution of DT7 is the same across categories of Provinces.	Independent-Samples Kruskal-Wallis Test	0,041	Reject the null hypothesis.
The distribution of DT11 is the same across categories of Provinces.	Independent-Samples Kruskal-Wallis Test	0,025	Reject the null hypothesis.
The distribution of DT12 is the same across categories of Provinces.	Independent-Samples Kruskal-Wallis Test	0,033	Reject the null hypothesis.

An additional test was conducted; however, in this instance, the general building grading was used as the dependent variable. Table 5.41 presents the observed findings. DT7 ($p = 0,039$); DT10 ($P = 0,019$); DT17 ($P = 0,030$) and DT18 ($P = 0,037$) all evidenced a statistically significant difference with a confidence level of 95% and 5% margin of error. It can be observed that DT7 (digital twins) presents the same outcome across the categories tested. While Appendix D presents the findings that indicates no statistically significant differences across the remaining DTs when evaluated using GB, the variation observed in Table 5.40 and Table 5.41 warrants further examination and presents a noteworthy deviation from the primary findings. Following which, an additional iteration was conducted. However, in this iteration, the dependent variable was changed to civil engineering (CE) company performance, and the results of the Kruskal-Wallis test with no changes to the confidence level and margin of error are presented in Table 5.42.

Table 5. 41: Independent-Samples Kruskal-Wallis Test across General Building companies of South Africa.

Null Hypothesis	Test	Sig. ^{a,b}	Decision
The distribution of DT7 is the same across categories of General Building	Independent-Samples Kruskal-Wallis Test	0,039	Reject the null hypothesis.
The distribution of DT10 is the same across categories of General Building	Independent-Samples Kruskal-Wallis Test	0,019	Reject the null hypothesis.
The distribution of DT17 is the same across categories of General Building	Independent-Samples Kruskal-Wallis Test	0,030	Reject the null hypothesis.
The distribution of DT18 is the same across categories of General Building	Independent-Samples Kruskal-Wallis Test	0,037	Reject the null hypothesis.

Table 5. 42: Independent-Samples Kruskal-Wallis Test across Civil Engineering companies of South Africa.

Null Hypothesis	Test	Sig. ^{a,b}	Decision
The distribution of DT3 is the same across categories of Civil Engineering	Independent-Samples Kruskal-Wallis Test	0,017	Reject the null hypothesis.

A rigorous correlation assessment of the various digital tools used in the construction industry is conducted using project productivity, which in this test is used interchangeably with project performance as was coded during the data imputation process. This is conducted in this iteration style. A Spearman's test for correlation was used to interrogate the existence of relationship or lack thereof, across the various digital tools and project performance. With $P < 0,01$ it can be observed across the results that different digital tools (DT1 – DT18) have a positive statistically significant correlation. However, in the observation of the results where P

$< 0,05$, it can be observed that DT9 ($r = 0.254$), DT10 ($r = 0.258$) and DT16 ($r = 0.226$) present an even stronger statistically positive correlation. The positive, statistically significant relationships observed in this iteration were used to address H1. The results provided empirical support for the hypothesis, leading to its acceptance.

		Project Performance	DT1	DT2	DT3	DT4	DT5	DT6	DT7	DT8	DT9	DT10	DT11	DT12	DT13	DT14	DT15	DT16	DT17	DT18
Project Performance	Pearson Correlation	1																		
	Sig. (2-tailed)																			
	N	92																		
DT1	Pearson Correlation	0,065																		
	Sig. (2-tailed)	0,561																		
	N	82	82																	
DT2	Pearson Correlation	0,004	.649**																	
	Sig. (2-tailed)	0,970	0,000																	
	N	82	82	82																
DT3	Pearson Correlation	0,039	.448**	.645**																
	Sig. (2-tailed)	0,732	0,000	0,000																
	N	81	81	81	81															
DT4	Pearson Correlation	0,123	.532**	.706**	.653**															
	Sig. (2-tailed)	0,271	0,000	0,000	0,000															
	N	82	82	82	81	82														
DT5	Pearson Correlation	0,051	.663**	.675**	.561**	.792**														
	Sig. (2-tailed)	0,648	0,000	0,000	0,000	0,000														
	N	82	82	82	81	82	82													
DT6	Pearson Correlation	0,100	.499**	.344**	.460**	.423**	.491**													
	Sig. (2-tailed)	0,369	0,000	0,002	0,000	0,000	0,000													
	N	82	82	82	81	82	82	82												
DT7	Pearson Correlation	0,137	.688**	.640**	.405**	.645**	.683**	.561**												
	Sig. (2-tailed)	0,218	0,000	0,000	0,000	0,000	0,000	0,000												
	N	82	82	82	81	82	82	82	82											
DT8	Pearson Correlation	0,104	.571**	.519**	.406**	.535**	.527**	.402**	.742**											
	Sig. (2-tailed)	0,350	0,000	0,000	0,000	0,000	0,000	0,000	0,000											
	N	82	82	82	81	82	82	82	82	82										
DT9	Pearson Correlation	.254*	.593**	.575**	.429**	.475**	.524**	.521**	.632**	.674**										
	Sig. (2-tailed)	0,021	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000										
	N	82	82	82	81	82	82	82	82	82	82									
DT10	Pearson Correlation	.258*	.383**	.571**	.362**	.387**	.384**	.239*	.509**	.528**	.519**									
	Sig. (2-tailed)	0,019	0,000	0,000	0,001	0,000	0,000	0,031	0,000	0,000	0,000									
	N	82	82	82	81	82	82	82	82	82	82	82								
DT11	Pearson Correlation	0,173	.558**	.529**	.285**	.461**	.536**	.465**	.606**	.499**	.631**	.542**								
	Sig. (2-tailed)	0,120	0,000	0,000	0,010	0,000	0,000	0,000	0,000	0,000	0,000	0,000								
	N	82	82	82	81	82	82	82	82	82	82	82	82							
DT12	Pearson Correlation	0,160	.581**	.559**	.391**	.423**	.501**	.433**	.619**	.588**	.652**	.623**	.642**							
	Sig. (2-tailed)	0,150	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000							
	N	82	82	82	81	82	82	82	82	82	82	82	82	82						
DT13	Pearson Correlation	0,008	.252*	.295**	.380**	.248*	0,201	.365**	.277*	.225*	.378**	.322**	.245*	.270*						
	Sig. (2-tailed)	0,944	0,022	0,007	0,000	0,025	0,070	0,001	0,012	0,042	0,000	0,003	0,027	0,014						
	N	82	82	82	81	82	82	82	82	82	82	82	82	82	82					
DT14	Pearson Correlation	0,121	.709**	.608**	.431**	.528**	.608**	.419**	.717**	.659**	.621**	.487**	.554**	.642**	.298**					
	Sig. (2-tailed)	0,278	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,007					
	N	82	82	82	81	82	82	82	82	82	82	82	82	82	82	82				
DT15	Pearson Correlation	0,107	.299**	.431**	.552**	.537**	.460**	.430**	.349**	.429**	.420**	.362**	.408**	.335**	.511**	.395**				
	Sig. (2-tailed)	0,341	0,006	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,000	0,001	0,000	0,002	0,000	0,000				
	N	82	82	82	81	82	82	82	82	82	82	82	82	82	82	82	82			
DT16	Pearson Correlation	.226*	.570**	.665**	.429**	.589**	.541**	.429**	.765**	.707**	.729**	.625**	.672**	.621**	.353**	.714**	.521**			
	Sig. (2-tailed)	0,041	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,000	0,000				
	N	82	82	82	81	82	82	82	82	82	82	82	82	82	82	82	82	82		
DT17	Pearson Correlation	0,146	.600**	.627**	.434**	.560**	.550**	.393**	.703**	.631**	.558**	.469**	.627**	.500**	.308**	.617**	.370**	.656**		
	Sig. (2-tailed)	0,190	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,005	0,000	0,001	0,000		
	N	82	82	82	81	82	82	82	82	82	82	82	82	82	82	82	82	82	82	
DT18	Pearson Correlation	0,026	.450**	.504**	.397**	.511**	.446**	.381**	.662**	.610**	.530**	.383**	.381**	.447**	.429**	.575**	.450**	.626**	.702**	
	Sig. (2-tailed)	0,818	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	
	N	82	82	82	81	82	82	82	82	82	82	82	82	82	82	82	82	82	82	82
* . Correlation is significant at the 0.05 level (2-tailed).																				
**. Correlation is significant at the 0.01 level (2-tailed).																				

5.5.2 Validating Hypothesis two

Hypothesis 2 posits that a statistically significant relationship exists between external factors and the reluctance of construction companies in South Africa to adopt and implement digital technologies, with such reluctance subsequently impacting productivity. Leading from hypothesis one and the nature of the distribution of the study, Kruskal-Wallis test was also used for this validation. Additionally, a confidence level of 95% and a 5% margin of error were applied. However, Table 5.43 reports that OC9 (economic changes) is the only construct expressing a statistically significant relationship ($P = 0,004$) across GB and civil engineering organisations in South Africa. Moreover, amongst the other tested constructs, no statistical significance is observed. This is further corroborating the null hypothesis within this category. Appendix F shows a full set of results for other tested variables.

Table 5. 43: Correlation across various external factors on digitisation and project productivity.

Null Hypothesis	Test	Sig. ^{a,b}	Decision
The distribution of OC9 is the same across categories of Provinces.	Independent-Samples Kruskal-Wallis Test	0,004	Reject the null hypothesis.

The last category of external factors (technical factors) evidence that T7 ($P = 0,035$) and T11 ($P = 0,015$) are the only two factors that express a statistically significant difference and thus rejecting the null hypothesis. Table 5.44 shows the observed results and Appendix I expresses all the other variables where a 95% confidence interval and 5% margin of error was adopted in the analysis. The other iterations utilizing GB and civil engineering revealed that T8 ($P = 0,47$) is the only variable with significant statistical difference within GB. All other variables validate the hypothesis in civil engineering (Appendix H).

Hypothesis two is validated by observed PLS-SEM analysis expressed in Figure 5.6 which depicts a statistically significant relationship between environmental factors and project productivity and as a result, refuting the null. This is corroborated further in Table 5.25.

Table 5. 44: Correlation across technical factors on digitisation and project productivity.

Null Hypothesis	Test	Sig. ^{a,b}	Decision
The distribution of T7 is the same across categories of Provinces.	Independent-Samples Kruskal-Wallis Test	0,035	Reject the null hypothesis.
The distribution of T11 is the same across categories of Provinces.	Independent-Samples Kruskal-Wallis Test	0,015	Reject the null hypothesis.

5.5.3 Validating Hypothesis three

Table 5.45 represents the validation of Hypothesis three when correlating (analysing) the effect on project productivity against academic qualification as an independent variable. The validation of this hypothesis utilising academic qualifications is upheld by Dixit *et al.* (2017) in positing that a significant relationship exists between expended levels of project productivity and the increase in attainment of academic qualification among the construction professional team. As demonstrated in Hypothesis One concerning the impact of digital technologies as a moderating factor on project productivity, the validation of Hypothesis Three will adopt the assertion proposed by Dixit *et al.* (2017). Table 5.45 presents the results of the analysis, and it can be seen that at 95% confidence interval, the observed p-value of 0,883 is reported. This further corroborates the findings in Table 5.36 in that no statistically significant relationship is observed and consequently, not rejecting H3 (Null).

Table 5. 45: Correlation across Skill, knowledge and experience and project productivity across South Africa (Academic qualification as an instrument of measure).

Null Hypothesis	Test	Sig. ^{a,b}	Decision
The distribution of Project_Performance is the same across categories of Academic Qualification.	Independent-Samples Kruskal-Wallis Test	0,883	Retain the null hypothesis.

5.6 Chapter Summary

This chapter presented and analysed the questionnaire findings in relation to the study objectives. Respondent demographics indicated that most participants had 21–30 years of construction experience (28%), held BSc/Engineering/Diploma qualifications (40%), occupied directorial positions (50%), and specialised in general building projects (43%). Most respondents operated in Gauteng (40%), while Grade 6 contractors constituted the largest proportion of both general building (18%) and civil engineering (20%) respondents. The study assessed familiarity with digital technologies using the Mean, Relative Importance Index (RII),

Mean Item Score (MIS), standard deviation, and rankings. Mobile devices, ICT, IoT, BIM, and web-based project management systems were the most familiar technologies, whereas robotics ranked lowest. Environmental factors affecting digital adoption included adverse weather, material delivery delays, and unforeseen ground conditions. Organisational barriers comprised labour payment delays, material price fluctuations, and non-payment of labour, while technical barriers included incomplete drawings, design changes, and poor project design. Productivity was primarily measured through client satisfaction, quality, health and safety, project completion time, and cost. Key enablers of digital adoption were workforce training, professional collaboration, investment in digital technologies, and lean construction practices. Major barriers included financial constraints, high implementation costs, inadequate training, limited investment, and insufficient technical skills. Perceived benefits included improved communication, rapid information exchange, enhanced project performance, transparency, and productivity. PLS-SEM and SPSS analyses supported H1 but rejected H2, indicating that digital technologies did not significantly moderate the relationship between external factors and project productivity.

CHAPTER SIX: QUALITATIVE DATA PRESENTATION AND ANALYSIS

6.1 Introduction

This chapter reports on the data collected from the various research participants selected for interviews. The fundamental objective of conducting research interviews with the selected research respondents (A-K) was to elicit a depth of understanding with regard to the different digital tools used across the projects they are involved with. Additionally, probe further into the way these tools are used and at what level of project development are these tools being used (planning, designing and construction phase). This was to evaluate a stage in the development where optimum benefit is observed across the development of a project, or whether there was no benefit of use. Another point of inquiry was to assess the respondents' perceptions of the readiness and attitude towards adopting digital technologies in the South African construction industry. The other objective in conducting these interviews was to assess the degree of competency, financial feasibility, as well as organisational attitude towards adapting digital technologies. The modes through which these interviews were conducted were through Microsoft Teams and a face-to-face format. This was to ensure that a clear and acute representation of the respondents' answers are captured and automatically transcribed through the Microsoft Teams feature. Furthermore, this was to ensure that the limitation of distance and location did not deter the collection of necessary data for the research. Face-to-face interviews were recorded, and the responses were transcribed. Appendix B2 provides all the records of the respondents. A consent form was sent to all the respondents before the interview, and all provided verbal consent prior to the recording of the interviews conducted online and those conducted face-to-face. Eleven (11) respondents were specifically selected for this portion of the research. These respondents spanned CEOs, CMs, Qs, Health and safety specialists, Contracts managers, as well as entrepreneurs in the digital tools and software. The interviews were conducted between September 2024 – July 2025. The findings from the interviews are presented.

6.2 Data Presentation

This section reports on the demographic data of the respondents. This section also evaluates the various projects that the respondents have worked on, as well as the value these projects comprised. Furthermore, this section reports on the participants' perception of the readiness to fully digitise project systems across the construction industry in South Africa. Lastly, this section addresses the impact of externalities out of the control of the respondents, especially on the various digital tools applied or adopted.

6.2.1 Demographic data of the interviewees

Table 6. 1: Demographic data of the interviewees

Participant Code	Highest Academic Qualification	Job title	Years in the Industry	Professional Accreditation	Location in South Africa – Province	Interview Mode
A	BSc Honours	Project Manager	13	SACPCMP	Kwa-Zulu Natal	Online
B	MBA	Civil Engineer	25	ECSA	Western Cape	Online
C	BSc	Health and Safety specialist	5	SACPCMS	Western Cape	Online
D	BSc	Quantity Surveyor	2	SACPCMP	Western Cape	Online
E	BSc	Contracts Manager	25	SACPCMP	Western Cape	Face-to-Face
F	BSc	Project Manager	40	ECSA, SACPCMP	Western Cape	Online
G	MSc	Project Manager	25	ECSA, SACPCMP	Eastern Cape, Western Cape and Kwa-Zulu Natal	Online
H	Diploma	CEO	14	SACPCMP	Eastern Cape, Gauteng, Western Cape and Kwa-Zulu Natal	online
I	BSc	MD	20	SACPCMP	Eastern Cape, Gauteng, Western Cape and Kwa-Zulu Natal	Face-to-Face
J	BSc Honours	Quantity Surveyor	13	SACPCMP,	Limpopo, Eastern Cape	Online
K	BSc	Civil Engineer	26	ECSA	Western Cape	Face-to-Face

6.2.2 Interviewee project Information

Table 6. 2: Project Information

Participant Code	Highest value of the project	Project location in SA	Identified Software	Identified physical Technology	Stage of the project used
A	R1 billion	Kwa-Zulu Natal	Dim-X	Drone technology	Construction phase
B	R100 million	Western Cape	Financial Management System software	-	Planning and construction phase.
C	R300 million	Western Cape	Digital Permit System software	Drone technology	Construction phase
D	R1 billion	Western Cape	BIM, CCS, CANDY	Drone technology	Planning and construction phase
E	R210 million	Western Cape	PROCORE, BIM	-	Design and construction phase
F	R600 billion*	Western Cape	-	Material Development manufacture	Design and construction phase
G	R3,8 billion	Kwa-Zulu Natal	BIM, CCS, Primavera.	Drone technology	Design and construction phase
H	R7 billion	Western Cape	Health and Safety software	-	Construction phase
I	\$10 million	Western Cape	BIM, Catenda, Procore, Cloudfiler, ArCADiasoft	-	Planning, design and construction phase
J	R56 million	Eastern Cape	WINQs, DIM-X, QS Plus	-	Planning, design and construction phase
K	\$1,2 billion	Western Cape	MS Project, CCS and BIM	-	Planning and construction phase

6.2.3 Rationale – Data saturation

Qualitative research is prone to data saturation and this phenomenon applied though the collection of data for this study. Data saturation is a fundamental methodological concept in qualitative research and is reached when the continued collection of data no longer yields new

information, themes, patterns, or conceptual insights relevant to the research objectives (Fusch Ph D and Ness, 2015; Mwita, 2022). At this stage, additional interviews, fail to contribute substantially to the development of emerging categories or the refinement of existing themes (Fusch Ph D and Ness, 2015). Instead, the information obtained becomes increasingly repetitive, indicating that the phenomenon under investigation has been explored in sufficient depth and breadth. The attainment of data saturation suggests that the researcher has adequately captured the range of perspectives, experiences, and meanings associated with the study topic. As recurring responses and themes become evident across participants, confidence increases that the collected data provide a comprehensive representation of the research context. Consequently, further data collection is unlikely to enhance the analytical richness of the study or generate significant new findings.

In qualitative inquiry, data saturation serves as an important criterion for determining the adequacy of sample size and the completeness of data collection. It provides methodological justification for concluding the recruitment of participants and transitioning to the analysis phase. Achieving saturation enhances the credibility, trustworthiness, and rigor of the research by demonstrating that sufficient evidence has been gathered to support the study's interpretations and conclusions. Therefore, data saturation is widely regarded as a key indicator of the quality and robustness of qualitative research findings. For this study, 11 interviewees spread across South Africa were obtained. The emergence of consistent themes was expressed in the 8th Interview, though which a discussion with the study supervisor was convened. However, more interviewees responded before the data collection period and as a result, a total of 11 were considered adequate.

6.3 Presentation of identified digital tools and technologies

In the analysis and assessment of the research findings, one of the most critical components was the establishment of digital technologies that the interviewees were familiar with. This is to critically assess the familiarity, exposure, as well as perceived benefits of these technologies. Moreover, the study embarked on an expansive pool of reach in the selected interviewees, spanning a multitude of sectors of the economy. The findings are presented as follows.

It emerged from the responses that when a project is assessed across the critical integration of digital technologies, project managers are expected and exposed to a larger pool of resources.

This is to ensure that the program, as well as the financial component of the project, is acutely drawn, and costs are accounted for at each level of the construction project. This postulation is purported by Interviewee A when they reported that

“We, the construction project managers, use CCS for project management. This is to track the project productivity and also for tracking the finances from a contracting point of view. And then from the project management side, I’ve used MS projects and then we use a lot of MS Teams to conduct meetings. And then the Qs use a lot of BIM. They also use what we call Dim-X. We’ve also started to use a lot of drone technology, especially our risk assessors. They like to track risks by using this.” Interviewee A. However, Interviewee A emphasises that in the adoption of the varying technologies found on the projects they have embarked on, the larger component of such technologies is more software-based as opposed to physical (tangible) technological components.

This assertion was further purported by interviewee D when they stated that

“We’re currently using CCS and CANDY. That’s basically it. The only technological innovation we also have is using electronic signatures for appointments in the company I work for.” Interviewee D. This alluding to the fact that their specialisation on the project, is managing the program of works and the capacity under which they are able to do this, is the utilisation of software. This is the software that is specifically designed to map out the entire project schedule, while giving the elemental composition of the costs each activity is to expend.

However, interviewee E and expressed a different point of view in that as an entrepreneur that develops software specifically used in the project management fraternity (especially construction projects), they are in the business of developing specialised software and tools that are largely implemented on construction projects. They further purport that

“Currently we are in the development phase of a warehouse for [Retracted] and we’ve been using BIM software for both design and progress monitoring. The other software that we use is PROCORE.” Interviewee E. They further expand on this assertion in that

“As mentioned, we have a suite of packages aimed at the construction industry professionals. Our business website. Is [retracted], here you can see that we have cost management packages,

project planning software which can be used from inception of the project right through to the completion.” – Interviewee E. Congruent to the modus of software found prevalent across the respondents, Interviewee G states that

“Especially CCS and Primavera because they form part and parcel of how we plan for the project and execute a construction programme.” Interviewee G

This means a common thread can be established that in the side of works and cost management, there seems to be similar types of technologies (or software) being utilised in the industry. This can further be inculcated by Interviewee F and Interviewee H in stating that

“The technology used is laser scanners that go into an existing building and scan it so that we get the correct dimension for any other work that may be necessary. Another one is that we would use BIM, CAD, as well as Smart Materials.” Interviewee F

“So, we personally have developed our own auditing software. BIM-360 or Moderna.”
Interviewee H

However, not all Interviewees had a complete familiarity of tools used on site. Interviewee C expresses that, an integration of software and tangible technologies were used. This they further expressed that wearables were part of the various modes of technologies used on site. Moreover, Interviewee C reports that

“I’ve been exposed to drones. I’ve flown a drone over construction sites before. I have also been exposed to a digital permit system. Those are the ones. Digital permit system allows us to move away from the paper-based system to more of a digital system.” Interviewee C. Interviewee C and I largely purported that Health and Safety were a big concern on their projects and as a result, having a system that can easily identify risks, afford the construction team the liberty to mitigate this and/or evade the risk; was their biggest concern. Interviewee I reported that

“I largely used on projects has been BIM, drones and mobile devices. These are tablets. And wearables and even cell phones to actually survey an entire project. The ones that I have seen doing really well are BIM, Catenda, Procore, Cloudfiler, ArCADiasoft.” Interviewee I. They

expressed that different project managers can coexist at the same time on site and as a result, the compatibility of their wearables, tablets and software, can be incompatible with the one monolith of a software. As a result, they had a network of software that can easily be used by varying professionals involved on a project and have these products yield the same results. This is to minimise the time delay and completely eliminate the need for prolonged turnaround times when an RFI is actioned. From a QS perspective, Interviewee J expresses the same concept of amalgamating software in that

“I’ve worked with Win-QS. I have also worked with DIM-X as well as QS-Plus.” Interviewee J, this further means that delays were eliminated and impact on project success was minimised. The expressed digital utility and selection of software, substantiates that which is expressed by scholars which previously focused on this kind of study. Largely due to the connectivity, benefits and incorporating the different construction professionals for the common purpose of advancing the project and improving performance (Berlak *et al.*, 2021; Nassereddine *et al.*, 2022; Papulová *et al.*, 2022; Aigbavboa and Kissi, 2025).

In the analysis of the Interviewee’s responses, it was imperative for the study to generate a thematic structure extracted for frequently utilised key words by the interviewees, this is encapsulated and presented in Figure 6.1. Herein, the following section systematically analyses the themes as presented and corroborates this which the findings of literature for any congruency or negation of common synthesis. The analysis is carried out as follows.



Figure 6. 1: NVivo15 word cloud of aggregated interview folders

6.4 Perceived benefits of Digitalising project operations

A large portion of what constitutes benefits of application of digital technologies has been discussed in detail throughout literature (Berger, 2016; IDC, 2020; Berlak *et al.*, 2021; Tjebane *et al.*, 2022). Following which, the quantitative portion of this research analysed these and presented them in Table 5,10. Notwithstanding that, it is fundamental for the Interviewee's perceptions to be explored. The perception that digitalising construction activities improves productivity cannot be negates, however the validity of how that is expressed on a project is crucial. Interviewee A expresses the benefits this has had on their project in reporting that

"There was an improvement in the order that the program ran. There was also a significant reduction in errors from the professional team's side as we primarily used software that was similar from start to completion of the project. The one thing that I've found handy is the clash detection functionality." Interviewee A. In this assertion, Interviewee A reinforces the declaration made by Interviewee C when they stated that

"It will allow us to streamline a lot of the processes that we have on site; it allows us to operate in a more centralized way. This is where everyone can receive the same information. It'll allow

us to track our progress much better. It also allows for the integration and the involvement of all stakeholders. This will also make operations twice as fast.” Interviewee C. This shows that in streamlining construction activities, organisations are more inclined to utilise digital platforms. Additionally, the cost component which Aigbavboa and Kissi (2025) delineates as well as the interconnectedness of synchronising digital platforms for better project productivity as per Wyman (2018), is echoed by Interviewee D in positing that

“We used it in estimating the cost of the project and manage the progress of the budget spent. I’m in the commercial department. So, in estimating, we use CANDY to also draw the project program.” Interviewee D. In addition to that, Interviewee D further expands in that the integration of all this software allows for detection of any values that do not match and thus this can be easily remedied. Interviewee E presents a complication that each project is no exception to, which is the management of large teams of subcontractors. Furthermore, they reiterate the ease of detection in the case that should there be any detraction from original quantities, this can be detection in time for there not to be any detrimental effects that can halt the project (Aliu and Oke, 2023). This they posit by stating

“...this assists us in that we can measure quantities and ensure that any changes made, the client can also see in real time...I can state that using Primavera specifically, we have seen valuable improvement in productivity, especially on the project I am involved with now because its big has a lot of subcontractors.” Interviewee E

Visualisation as a component of modern development as advocated for by the use of VR and AR is gaining traction at a pace that some of the Interviewees have had experience with on their respective projects (Berlak *et al.*, 2021; Siddiqui, 2022). In assessing how Interviewees use this digital feature in their organisations, Interviewee H stated that

“It can give you 3D renders so that you can do coordination of the project program properly. They also allow the detection of clashes and all of that before you start building.” Interviewee H. And in addition to that, Interviewee I further theorised that

“This helped a lot when we wanted to do a visual inspection of a site, particularly through the defects phase. The great advantage of these is that you have the entire design team able to see

all the inputs required for the design of a development to be achieved.” Interviewee I

This assertion by Interviewee I proved to be pertinent in that the methodology under which they used VR combined all the construction professionals that were involved from the inception of the project, through to the completion of the project. It was this inclusion that allowed all professionals to keep up to date with any variances that potentially could arise and remedy this from the perspective of practical resolve.

6.5 Qualitative Data Analysis

In analysing the qualitative data, it was imperative to understand and extract all the observed themes across the research interviewees. These themes were generated through NVivo software where frequency of identification, causal effect to digitalisation and correlation to project productivity was significant to the interviewer. These themes are grouped and tabulated in Table 6.3 which represent the theme, the frequency of mention as well as the interviewer.

Theme	Frequency of mention	Interviewer
Legal Implications	3	B, G, H
Skills and training	6	B, E, C, D, F, K
Threads and concerns to digitalisation	7	A, C, D, F, J, G, H
Health and safety implications	3	C, H, K
Cost of implementation	7	A, C, G, H, I, J, K
Vocational uncertainty	2	F, J
Industry readiness	7	A, D, F, H, I, J, K
Barriers to digitalisation	6	A, B, F, D, G, H

Table 6. 3: Project Information

6.5.1 Legal Implications

A poignant concern which is reiterated across literature, is the concern regarding the legislature as well as the adoption of a different format that can encapsulate the current digital changes with the actual contracts used on construction projects such as the NEC contract (Aghimien *et al.*, 2021; Berlak *et al.*, 2021). Interviewee B expressed the need and stringent measures necessary for the procurement component of a construction project. They expressed this by

reporting

“When it comes to procurement, because it’s government, it’s governed by legislation. Everything must be according to legislation – even the use or implementation of any sort of technology that we might wish to use. You don’t use your own discretion outside the legislation, so we have, the municipal Financial Management Act which in parts controls how the contractor uses any systems of management.” Interviewee B.

Moreover, they advocate for the active participation of government to mandate this change as the construction industry absorbs a significant number of workers in South Africa (Barbosa, Woetzel and Mischke, 2017; StatsSA, 2022). In addition to that, Interviewee B further reports that

“It prescribes how you manage procurement and finances in general on a project. It also gives one a guideline of how payments are supposed to be done. Projects are centrally paid as each project is unique. It’s basically the interpretation of the FMA to the project. We do these projects within a certain contract like GCC, government general conditions of contracts, or the NEC or whichever contract is upheld for a particular project. You are governed by mainly those two the FMA and the contract under which you have contracted with the service providers.” Interviewee B. The same sentiment is echoed by Interviewee I in reporting that

“The other very pertinent issue is legislative concerns. There is no provision of approach of how a construction contract is to be used when technology is implemented on site. So maybe that is one of the impediments.” Interviewee I. This assertion by Interviewee I becomes a stark contrast to what other countries such as Netherlands, Denmark, Finland and Norway have already started legislating as a method to integrate digitalisation in their construction operations (Berger, 2016). Government contracts in these countries are legislated by government in postulating at least 50% of a contract awarded by government but be dedicated to entirely digital operation. This contrast is further posited by interviewee B when they stated

“If you look at projects, engineering projects in South Africa, most of them are government based. There is treasury which is the custodian of funds across the country. They are responsible for expenditure on everything and the framework on how to execute projects. The

Treasury is guided by ECSA.” Interviewee B. It can evidently be seen that government, to a large degree, must implement a legislative amendment that encourages digitalisation on projects. However, Interviewee G expands this further and posits that

“The new types of contracts in terms of the NEC contract, do not give an explicit way that we can use technology, so that is going to demand that a new contract is drawn which addresses this. And this can potentially take a very long time.” Interviewee G. This is to mainly ensure that all projects that utilises any of the NEC contracts, have a clause that explains the adoption criteria, degree of application and how this affects the labour component. However, Interviewee H reports *“My honest opinion is I don’t think it’s an either-or type of an answer kind of answer. I think it’s both. A big concern that I have with the built environment is how government and private sector operate. Either they do this jointly or completely different from one another.”* Interviewee H

And Lastly, Interviewee H reports that for this to work, both government and private sector can come together and assess the general construction industry and how it impacts the GDP of a country, and private sector with regards to how they use varying contracts.

6.5.2 Skills and Training

Figure 6.2 and Figure 6.3 provides a synopsis of the frequently used words in NVivo15 across Interviewees to further expand on this theme. This theme was also expressed in Chapter 3 when the need and efficacy for skill is necessary for the adoption and use of digital technologies. Across the Interviewees, the general consensus is that there is generally a lack of skill and training across construction professionals to be able to utilise some of the digital tools and technologies envisaged to be used in the industry. One of the Interviewees reported that

“You must have quite significant training and experience in terms of piloting licence. A lot of people have that experience and the licence. Then in terms of software itself, it must be integrated because you need to be able to understand how GPS coordinates work. It’s a bit difficult to map out and to integrate it, but in terms of flying the drone itself, it’s quite easy.” Interviewee A. One of the respondents expanded further on this is attributing the engineering fraternity to this crisis of lack of skill and training and this they reported that

“On that one, I would say we have a crisis in engineering. We’re talking about engineering

projects where we don't train our people well enough. So, we also have a problem where we rush people into responsibilities that are too big for their shoes." Interviewee B. Further to that, Interviewee E also reported that

"What has been important is that everyone has been given the opportunity to be trained on the software. Training used to be centred only around the middle management but in my view, foremen are as equally deserving." Interviewee E. This assertion is congruent with Interviewee G in positing that

"You have to be trained to use them. Over and above that, using resources that are doubling up as project management and design software can be challenging. Training is very important." Interviewee G. An opposing declaration is raised as Interviewee H posits that

"I don't think training is the sort of the inhibiting factor because I don't think there's tremendous cost there. There is a little bit, but it's not a crazy amount." Interviewee H. This means that in their perception, the cost expended by an organisation, is minimal as opposed to the long-term benefits of having trained employees and workers. Interviewee C reinforces that education is paramount to the use and comfortability of the construction professionals to the use and adaptability to digital technologies. *"The level of education required to operate the system would be the same as that of someone who is using the paper-based system."* Interviewee C. This sentiment is echoed by Interviewee D in positing that

"I think it's lack of skills development for one to actually know the software and what it can do for them. You need to learn it and be good at it. So, most of our colleagues are not really inclined to it, and the company doesn't have a drive to bring that skill into the employees. If we had it, it would improve productivity." Interviewee D.

However, Interviewee F strongly oppose the cited rationale that education is part of the inhibiting factor to the adoption and utility of digital tools. They further expand on this by hypothesising that

"No, I think if building environment becomes that way, we're going to have a huge amount of unskilled people. I think the building environment needs to understand its biggest asset. This is human labour, and labourers can be trained even if they are unskilled in a particular field

of the industry. Imagine the unemployment rate? And with that, especially in Africa, especially South Africa. If you want the economy to grow, you need as much workers as possible. Even if it means having to spend some money for the long-term benefit.” Interviewee F.

Similarly, Interviewee I posits that

“And technically, there is a lot of lack of education. It is not even knowledge because knowledge can always be acquired, but education is different. The utility of these tools requires a certain amount of education. Lack thereof, can significantly make it difficult to use these.” Interviewee I. this both negates and refute the absolute presentation and perception that without knowledge, there will not be any improvement in project productivity. This is inculcated further by the assertion made by Interviewee K

“I don’t think we have the experience that other countries have.” Interviewee K

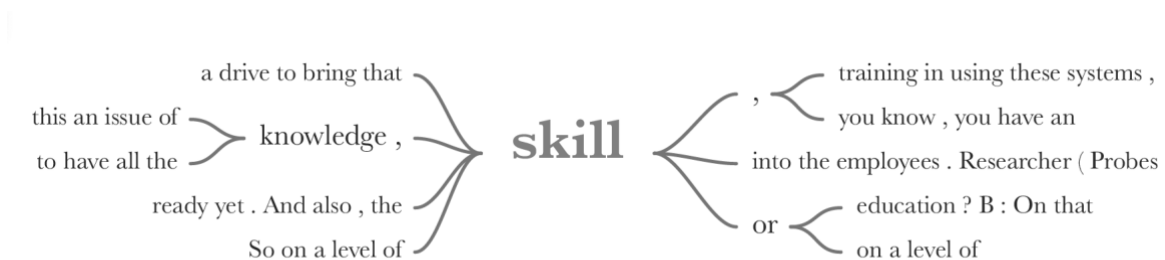


Figure 6. 2: Perception of significance of skill acquisition in the use of digital technologies (Word Tree – Nvivo15)

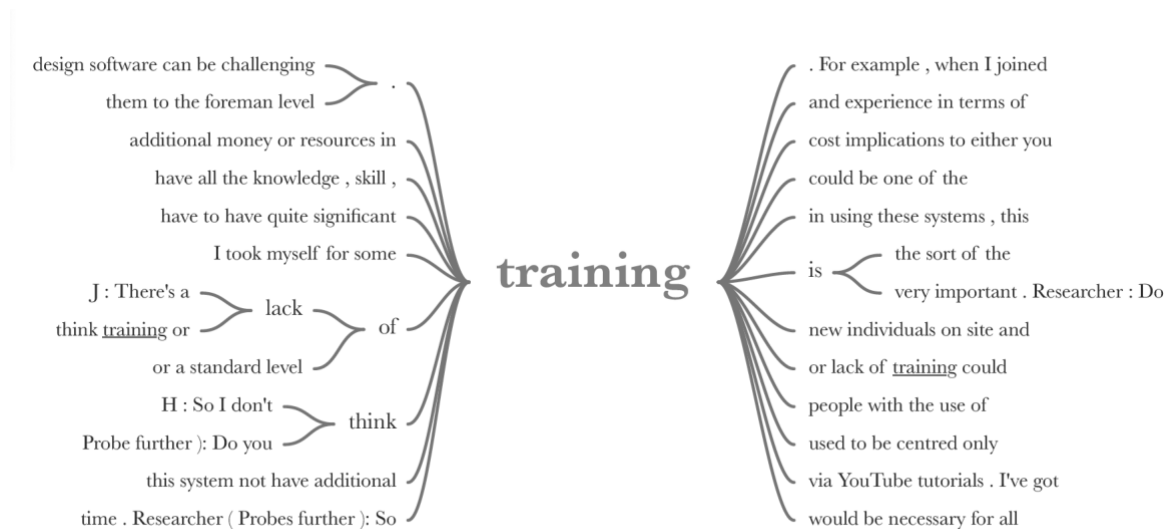


Figure 6. 3: Perception of significance of training required in the use of digital technologies (Word Tree – Nvivo15)

6.5.3 Threats and concerns pertaining to digitising

Across the assessment of one of the themes that emerged from the interviewees, was the prospect of concerns and threats that emanated. These were concerning the adoption, utility of adoption and the proficiency of the use of the digital technologies and tools. Interviewee A expressed that one of the areas of concern that have to be closely monitored, is the replication or duplication of a plant or structure which is designed digitally and now constructed in a different environment or locale. This assertion does not conflict with (Berlak *et al.*, 2021) when they stated that environmental conditions need to be assessed before digitising. This assertion made by Interviewee A is reported as follows.

The project I did was [Retracted]. It was a facility similar to a car manufacturing one. That was a car manufacturing facility, and it is a [Retracted] based company where they replicate the operations and model. They basically replicate the same standard in the same factory setting to all their factories, so the same designs. I think there was a detail that was omitted, something to do with the boom. I think if they had realised that the South African design fraternity doesn't not generally use tools such as virtual reality and BIM and addressed this before they even moved to South Africa, this would have been a game changer, but it was a disaster in this case because we had to go back to square one. Interviewee A. The same sentiment is shared by Interviewee J in lieu of how this replication also affects bills of quantities. This they assert by reporting

“We needed to go back and remeasure and capture everything to kind of replicate those documents and bill of quantities. That’s doing double work. And because we had already measured the bill, the fees for the bill increased.” Interviewee J. And in as much as this also poses other concerns, across the construction industry, organisationally there is also an emergence of comfortability by the workers to not veer off the systems and software they are familiar with. Interviewee D reports that

“I don’t know what the best way is the company can approach this, but on my end there’s a group of other quantity surveyors at my level that also prefers using other software than CANDY.” Interviewee D. And this is one of the continually referred concern and a core rationale found to geminate an aversion across the industry (Agdas and Ellis, 2010).

Interviewee F expresses a social issue which this study did not intend to explore. However, for the purpose of this intrinsic issue formulating the approach and willingness of construction organisations to digitise, it is discussed. Interviewee F reports that.

“The issue I find across South Africa in particular especially since I deal with smart material components, we face a lot of cultural issues. The one example which I’m going to give is that of a house. If we introduce the concept of a smart design that simulates a shack, a lot of end users tend to not even want to take residence in that because culturally, the idea of a house is considered a brick-and-mortar type. I deal with drywalling. We could probably give end users a much better house with Drywalling, but that doesn’t fall into their zone of comfort because a house must be made out of bricks.” Interviewee F. Intrinsic to the post-apartheid promise made by the then government of providing social housing (Ofori *et al.*, 1996a), the notional expectation was a four-wall structure. Interviewee F expresses that this expectation has woven itself into the nature that the aversion of any form of structure that doesn’t emulate that, does not count as a house. Which they reinforced with the smart material they use on their developments. This proclamation is further corroborated by Interviewee C in reporting that

“You know our industry is sort of still very much brick and mortar. Usually on site, we do often get supervisors that can easily adopt these tools, especially digital permit, but they always complain about connectivity or their data and so it’s not used to its full potential.” Interviewee C.

A commonality is observed through Interviewee G, H and J in that the security and storage of data is a concern that for any adoption of software, firm precaution has to be exercised and guaranteed by the service providers or the owners of this digital software. The concern is evidenced as cybersecurity concerns. Interviewee G expresses that

“The other concern is the storage of data and using it in the cloud-based manner. We had a meeting few weeks back and cybersecurity was one of the items that was a discussion, and this can sometimes be an issue or reason to not completely use online systems.” Interviewee G. In addition to that, Interviewee J expresses the same reaction in reporting that

“The other thing to consider with these sorts of systems is the ways which information can be leaked or just disappear. And once we deal with the information leakage, we deal with intellectual property now. People are going to be resistant to put project details and critical information in a software-based network because I don’t think we can definitively say that companies can control cybersecurity firmly.” Interviewee J. This further means that some form of authentication and guarantee is required in order to provide construction organisations and personnel surety in the fact that the data security will not be leaked and dispersed to third parties. However, Interviewee H expresses that

“Our app runs through the Microsoft ecosystem and it’s Microsoft responsibility to keep the data centre up and running. As long as I have a mobile device with Internet connection, I can utilise it even if there isn’t power. I can use all of that software from my cell phone on normal data plan, so it does have an influence, but I don’t think it’s major.” Interviewee H. Interviewee H distinguishes that the onus of ensuring and securing any project data, is dependent on the service provider used (*Microsoft*). They further express that part of the main reasons they developed their own system, is to scrutinise the probability of these kinds of concerns and mitigate them from the onset before they become significant detractors to project success. Moreover, the running and upkeep of the data (and storage) is guaranteed before the initiation of any project that uses their software package.

6.5.4 Health and Safety

Embedded within the inquiry of the study, is a need to understand if the application of digital technologies impacts the performance of a project across all its spheres. This is not limited to health and safety as a crucial part of the profitability matrix of a project's success as per Table 5,10. Figure 6,4 evidence the frequency of the use of health and safety across the Interviewees. In lieu of that, an interrogation into the Interviewee's responses was sought. Respondent C who primarily operate and manage the safety component of a project, stated that

“With the digital permit system, they'll tell us that we'll be building scaffolding access dry portion of the brickwork in this passage. On the checklist, they'll tick scaffolding. They'll also tick harness, lift signage and lift barricading. So that once that information is received by the client, I as the health and safety officer at [Retracted] can say, at [Retracted] building they're going to be doing brickwork from floor level XYZ and they'll be using this kind of supervision and permit letter for working at heights, thus I approve this activity.” Interviewee C.

A digital permit system as a repository and a permit allowing hazardous activities to be carried out on project under strict and rigorous conditions is employed. Furthermore, Interviewee C expands that with the use of this permit, activities that on average would demand a stringent paperwork, now demands less. Furthermore, the central team on a project are trained, alerted and undergo a risk assessment procedure that affords them the expertise and knowledge to carry out these activities so as to not delay any components of a project. This is assertion tackles Smallwood *et al.* (2020) hypothesis that an evidenced way in which Industry 4.0 affects health and safety, must be a collegial endeavour that explicitly outlines risks and provide mitigative measures of how to deal with the said risks. Additionally, Interviewee C's reporting coincides with an assertion made by Papulová *et al.* (2022) in expressing the dynamic nature of a construction project and advocating for the flexibility of the adopted tools to withstand and transpose to the various project conditions.

A concern expressed by Interviewee H was that accessing some of the documents can attribute an aversion by the organisations to adopt digital tools. They further report that

“The first reason is the speed in which the reports are available, but the other reason is because documents, drawings, variation orders and health and safety reports are now sitting in a digital

format and in a clout-based repository.” Interviewee H

However, they further express that one of the benefits of having a clout-based repository for all the project documentation, is the ease of access. This they delineate within the context of health and safety as safety is a core concern when dealing with an online based network. Additionally, they advocate that storing data in this way allows for analysis and assessment of data (project variations) in real time when they reported that

“With these predictions, you can say listen, If I follow this observed trend or these items, you can easily see that we are going to have a problem if we keep operating in this way. This means you can then be very proactive in mitigating risks and preventing accidents.”

Interviewee D.

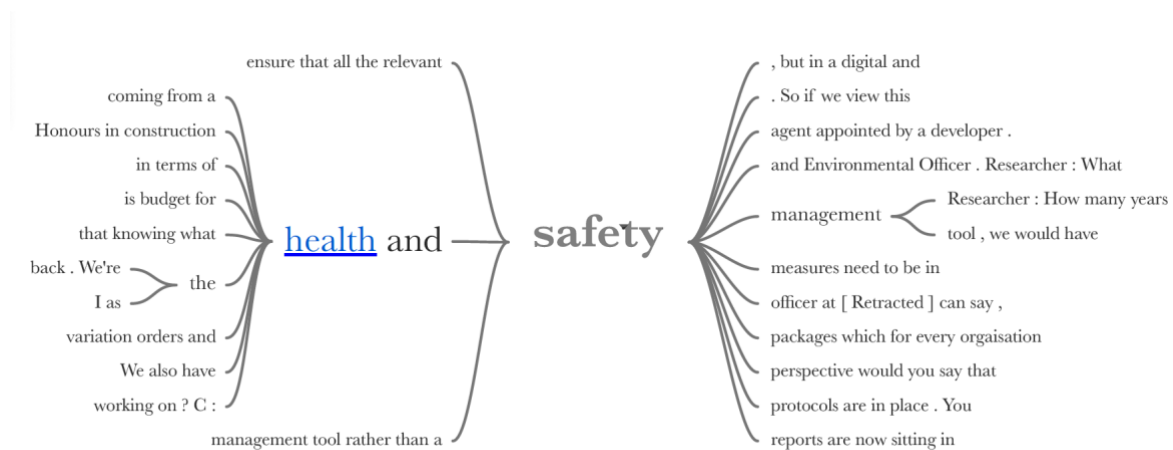


Figure 6. 4: Impact of digitalisation on health and safety (Word Tree – Nvivo15)

6.5.5 Cost of Implementation and adoption

Cost implications of digitising is a significant point of contention across Interviewees as it evidenced three-pronged perspective. As opposed to the quantitative analysis, this prospect was divided in this section. Interviewee A, C and G expressed a common observation across the projects they embarked on and unilaterally agreed that costs are not an issue as perceived by literature. However, this has a lot to do with the organisational attitude, propensity of workers to exploit the option to digitise as well as the measurable output that can be observed on projects and subsequent to that, the project profitability when digitalisation is adopted.

“So, there’s two sides to this now. In the one, it’s not that cheap, it’s not cheap to buy the software and it is also not cheap to access the license to operate it. Don’t mind us that operate without a license, but you actually need to have an operating licence. I think it’s a certain aviation licence. And one must have this license because obviously you are roaming in space where helicopters, planes and all of that.” Interviewee A

“I think it’s something that can be done, it’s just that we are not fully ready in terms of the cost factors or the cost implications.” Interviewee C.

“Not really because companies such as [Retracted], which come from Canada, UK and Australia, have helped us to really step forward and adopt these new tools and software to improve the project cycle and in some cases, improve the quality that we produce.” Interviewee G.

As can be observed from their responses, there are great benefit to adopting digitalisation and furthermore, the company’s objective, plays a role in how this is rolled out (Interviewee G). This further exposes the construction industry to shortfalls that are eminent (Mohd Nawi *et al.*, 2014) across the industry, as well as the fragmented nature. This becomes a point to reconsider as it was inter-alia purported by (Meintjes *et al.*, 2007; Riazi *et al.*, 2020) that the operations of a construction industry seem to function in silos as opposed to one network of a system.

On past projects where a need for BIM or such software was necessary, we would have to outsource this, and the cost was just not worth it because it was a lot. Again, with our company, we don’t mind spending money towards something that’s going to make us better with time. So cost is not really a factor at the moment. If as an MD or CEO you are open minded to the change innovation can bring in the long run, the rewards surely are worth the spending. Interviewee E.

The other polarity that can be observed, is that which is reported by Interviewee J, K and I. their stance is that organisations are apprehensive and often unwilling to digitise citing cost component. Furthermore, the costs and financial implications of having operational licences of some of this software, can be expensive and as a result, it is hardly the case that organisations are forthcoming about digitising. Additionally, Interviewee I expresses that in as much as

organisations may want to digitise, the added cost of maintenance of these software or tools (wearables, tablets, drones and surveying equipment), have to be taken into consideration. Failure of which, these may see a dilapidation of these resources and as a result, become redundant. These assertions they made by reporting as follows

I also find that the company doesn't want to spend additional money or resources in training people with the use of software. Yes, definitely. I also think the cost of implementing any form of technology is a big issue. Interviewee J.

The expense to keep this software and always having to update it. Licenses are expensive, especially if a new version of a system that one has been using comes out. Interviewee K

And perhaps one can add the expense that is related to the cost of utilising these tools. I mean ordinarily, one would need a licence to have access to the full suite of this software. Interviewee I.

And lastly, the Interviewee H expresses that in light of the cost component, cost of maintenance as well as training costs; the best alternative for their organisation, was to develop their own software. They report.

My reason for developing our own is primarily exorbitant licencing cost. In comparison to other software such as BIM, we find that ours tend to be quite expensive. Interviewee H.

Interviewee H operates which a specific type of technology which they are rolling out in the construction industry. The technology is embedded with capabilities to withstand weather, network malfunctions as well as the quality of being user friendly. With that in mind, it was imperative to by-pass the need for licencing and create their own. Furthermore, this ensued that they could have their own mark-up and pricing mechanisms to have this system operate at their own instructions. As a result, no one resolve of impact the respondents equally.

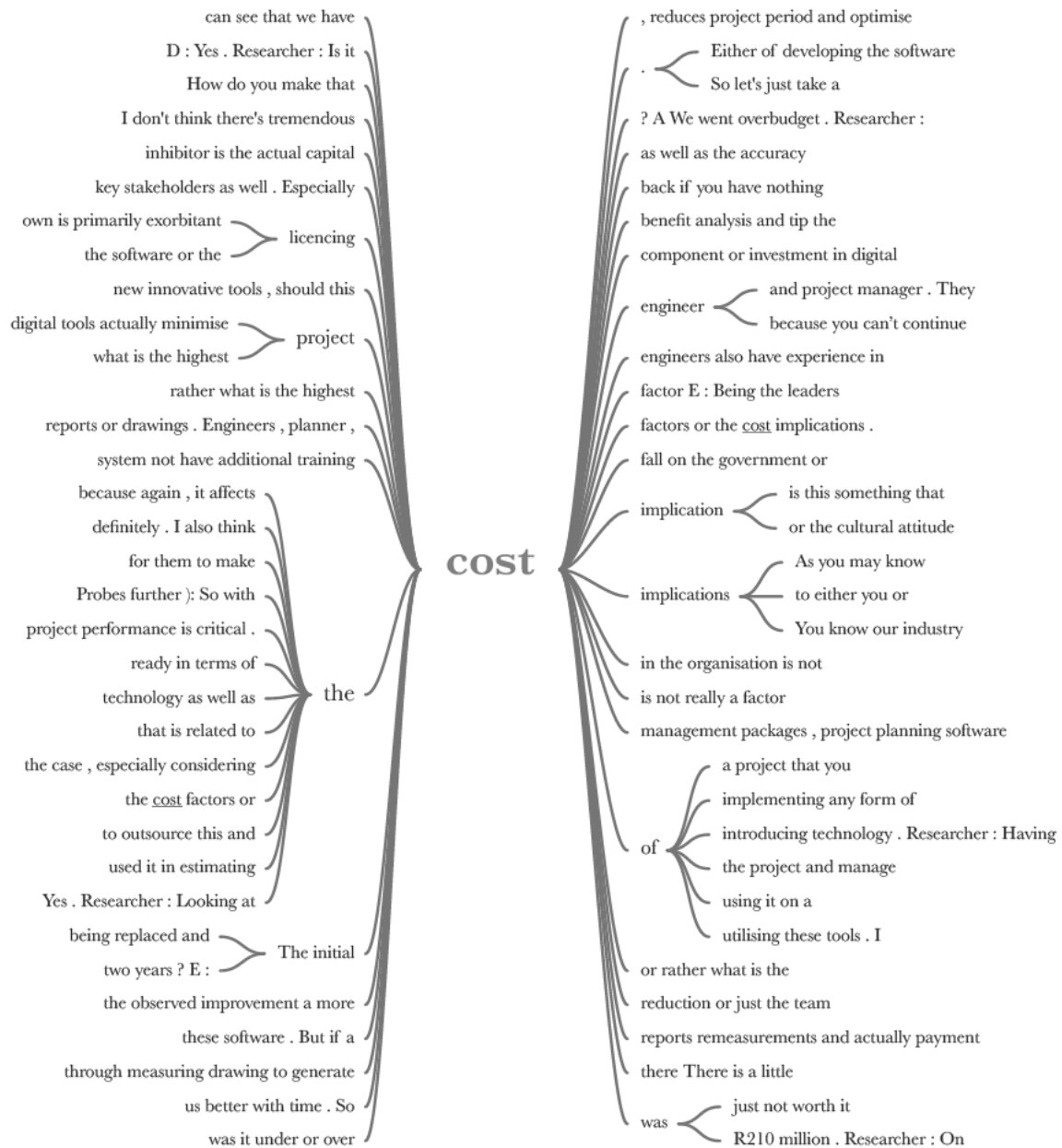


Figure 6. 5: Digitalisation and impact on cost when implemented across organisations and projects in South Africa (Word Tree – Nvivo15)

6.5.6 Vocational Uncertainty

The interrogation of literature in Chapter 2, expresses a concern that was prevalent across scholars which was the uncertainty in job security and retention in the advent of digitalising the construction industry. This further assessed in conjunction with the reported skilled and unskilled populous being absorbed by the industry for employment opportunities (Barbosa, Woetzel, Mischke, *et al.*, 2017; StatsSA, 2022). This theme was raised in lieu of the

employment statistics released by (StatsSA, 2025). The first quarter of 2025 reported a decrease in jobs across the five (5) largest industries which are: Trade (194 000) followed by construction (119 000), private household (68 000), community and social services (45 000) and lastly mining (35 000). These decreases in jobs point to the inquisition of the fundamental causes. As evident, the construction industry being the second largest industry to present a significant loss in jobs, Interviewees reported that this can be related to digitalisation. Interviewee F reported that

“I think if building environment becomes that way, we’re going to have a huge amount of unskilled people. I think the building environment needs to understand its biggest asset. This is human labour, and labourers can be trained even if they are unskilled in a particular field of the industry. Imagine the unemployment rate? And with that, especially in Africa, especially South Africa. If you want the economy to grow, you need as much workers as possible. Even if it means having to spend some money for the long-term benefit. The thing is if we keep on building. Let’s say infrastructure projects and any other kind of structure, we are constantly employing people and the people we employ can do things without formal education. Those with formal education tend to go for a senior role. So, it’s a completely different way of looking at things I know.” Interviewee F

Interviewee J further expressed that the use of AI or any form of digital technologies which are beyond or more advanced than the ones currently being used in the quantity surveying industry, this can significantly affect the profession. They further report that

“...the architects are further ahead with implementing technology or software. But in terms of quantity surveying, I think where the challenge is with QS is embracing change as well as fear that its implementation is going to replace your job.” Interviewee J

Interviewee J links the cost component as a deterrent to the job loss eminent and potentially probable in the construction industry. Interviewee J expresses that

“How do you make that cost back if you have nothing to benchmark it against? Remember this is a new system that you are introducing. I think those are the two biggest factors, job loss or being replaced and the initial cost of introducing technology.” Interviewee J

6.5.7 Industry Readiness

One of the areas of focus was the personal evaluation of the Interviewees and their perceptions of the readiness of the South African construction industry to digitise. A further polarisation of responses was collected. Interviewee A, D, F and I unanimously shared the reaction that a significant amount of restructuring across the South African construction industry is needed. This was further followed by the underlying shift of readiness to the private sector, as the sector is considered to be more controlled, organised and better funded. Furthermore, the shared sentiment pivoted about the comparative nature of other parts of the world such as China. This comparison was followed by the adaptability, investment prospects as well as the expansive infrastructure provided by the first world countries to digitise (Wyman, 2018). The four Interviewees reported their perceptions as follows

“100% no. Maybe the public sector is not ready, but portions of the private sector are ready.”
Interviewee A

“I’ve seen a lot of stuff online and when I look at other countries like China, those guys are ahead of time. The things that we are reluctant to start doing now, they have outgrown. I still maintain we are not ready yet. And also, the skill, you know, you have an old guy on site who is just not interested in change. Maybe the other reason why we are not ready is because it’s time consuming.” Interviewee D

“I don’t think so. This is mainly just observing the nature of the business. If you look at a new building, the likelihood of electricity being there or that sort of stuff initially, is not there. I don’t think that will ever happen. I really do not think the built environment is going to be fully digital in any sort of way. I just think that’s just the nature of the business.” Interviewee F. The assertion remains that from a skills perspective (Smidt and Jokonya, 2022), quality of education and propensity to exposure of digital tools (and) the nature of the construction operation; the construction industry in South Africa still has more growth to do. This is further asserted by Interviewee K when they reported

“There is still a long way to go.” Interviewee K

A contrasting perception from that expressed by Interviewee A, D, F and I was that evidenced

across Interviewee C, E, G and J. Within this perspective, these Interviewees shares that the industry is has over the years advanced with regards to the digital adoption. This is purported by Interviewee J when they stated

“Well, the attitude to adopt it was very good. Yes, it was. It was very positive. A lot of companies are seeing it as a better way of operating in the future.” Interviewee C. Corroborating this was Interviewee E when they stated that their organisation has in the previous decades been on the forefront of leading digital implementation. This they further reinforce in stating that part of the reputation and the organisation of consideration across large projects in South Africa, is because of this organisational attitude. In their postulation, they stated

“I believe we are. I mean, as I’ve said to you when we discussed this previously, our company [Retracted] is playing in its own league at the present moment when we talk about digitalising the construction industry. Being the leaders in how we execute our work with our mission always being to achieve excellence, this makes me confidence that South African is ready.” Interviewee E. Following which, Interviewee J draws a parallel in that other sectors of the built environment have already digitised their operations. They report that

“Architects and maybe engineers may not feel comfortable uploading their detailed drawings on a system that they cannot control. In me saying we are not ready as a South African construction industry, I believe this is something that still needs a lot of work.” Interviewee J.

“I mean, I think we have already started using some of them. There is a level of appetite for the South African construction industry towards adopting technology. But to go fully digital, I don’t think we are there yet.” Interviewee G. This this further resonates with (Riazi *et al.*, 2020) assertion regarding the silo methodology of the construction industry’s nature.

A last perspective provided by Interviewee H is that

“That is a very difficult question to answer because of the broad landscape of the South African construction industry. What I mean by that is not all pockets of our industry are the same. You get different rural residential - let’s call them cheaper developments. This is where single property owners develop either for themselves just to have an asset. Some also develop to either

rent out or sell. And in that type of clients and contractors, they are happy to carry on in the current status quo. Their argument is that if it's not broken, we're not going to fix it. Then you get a next tier where it is somebody who this is their business and occupation to develop. But it's still not on a grand scale, so they'll do one project at a time or one project a year, and they will be happy." Interviewee H.



Figure 6. 6: Construction Industry's preparedness in utilising digital technologies (Word Tree – Nvivo15)

6.5.8 Barriers to digitising in South Africa

Amidst variables that deter the construction industry from being able to digitise, is a set of barriers which further was evidenced as a theme across interviewees. Figure 6,7 expresses a word tree that was used as a guide to extract these themes across the interviewees. The findings of these perceived barriers did not differ from those that are cited in literature (Loraine and Williams, 2000; García de Soto *et al.*, 2022; Smidt and Jokonya, 2022). Unanimously, all the respondents shared the perception that the construction industry experiences numerous barriers in the attempt to adopt digital technologies across operations. The interviewees express these barriers as follows

“Yes, it is that's AI thing. That's the biggest barrier. That I could tell you because to be able to plot a site from the beginning is so imperative. So, if you're unable to plot the GPS coordinates, just basic site mapping of where it is, that's going to be a bit difficult activity to

learn at a moment's notice. And then you also must be able to calculate and know your basic quantities of volumes. Mainly because the biggest thing that you can use this technology for, is management of risk on site. I know the one guy that uses it. He's our risk assistant."

Interviewee A

Firstly, if you look at project identification. You need to define your project and monitor the progress as closely and accurately as possible. Another thing is the contractor tendering law. That's one of the major problems for contractors. The adjudication and award process normally go to the contractor with the lowest price and yet a host of other financial variables are not included. This often pose a serious issue as proving the contractor's competence can be difficult. So that is a risk. However, a tightening of tender requirements can significantly prevent this. But then the adverse can also pose a serious issue. Interviewee B

The barriers would be the adoption of technology as well as the cost implications. Interviewee C

I think it would be learning the use of software as a person that is not comfortable with technology or large programmes. One must learn how it works so that they can use it to the best of its capabilities. Interviewee D

With regards to data, honestly everyone has data nowadays, so we don't have any resistance towards access or someone not being able to afford data as a way to not work. Interviewee E

Remember the construction industry is still very old school. And usually, the sentiment is that they've always been doing things this way for a long time, and they don't see the need to change. Interviewee F

The challenge will be that sometimes change in site management such as when project managers are replaced, can become a bit of a time-consuming exercise to ensure that the new project manager understands the systems already in place. The other issue is cases where you have a new team that has been mobilised to your project. This usually demands induction to systems and software and update them on the project specifications and software being used. This takes time. The other concern is that there is no standardisation everyone does their own

thing, that makes it hard to completely adopt to something we all don't understand from the same point of view. Interviewee G

I think the biggest inhibitor is the actual capital cost. Either of developing the software or the licencing cost of using it on a monthly basis for a client that uses it. So, people are very resistant to change. Only when they have sort of finished the onboarding process and started utilising a new tool, then their aversion to that specific tool subsides. From a price perspective, the expense can be seen as an obstacle or a barrier. But people also don't like using [Retracted] products, and they just then prefer to stick to already existing methods, even if the new method is better but expensive. This becomes a hindrance to the project. Taking that into consideration, if we were then to add another tier, call it the digital tool into the public sector, it will be very difficult. I don't know if public sector is necessarily ready for that. They can barely execute projects in time and on budget. Interviewee H

From an organisational perspective, I find that some companies are comfortable with not using or integrating technology at all in their activities. Innovation is not always appreciated, and I find that a lot of people are not usually comfortable to use a different kind of technology that might require them to spend more time learning, whereas they could revert back to systems they are comfortable with. Interviewee I

There's a lack of training. For example, when I joined the last company which I worked for, I had to switch from using QS-plus to using Win-QS and I'm not familiar with Win-Qs. I guess we can also add the fact that there isn't a standardised software that was or that's used by the whole industry. So you'll go to Durban, and they will be using a different software to that being used in Cape Town, and that will also be different from what is being used in the Eastern Cape. That sort of standardisation would be a good start, but as it stands right now, it's very much a barrier. Interviewee J

The reported responses across Interviewees A – J expresses an already contrived perspective hypothesised through literature. The cost of capital outlay in the procurement of digital technologies is considered paramount across respondents. Furthermore, training of the respondents and upskilling the workers also pivots as a critical barrier which impacts time and as a result the execution of a construction project. Additionally, Interviewee F and G note that

traditional methodologies of executing a project and changes in organisational structure are also fundamental to the slow pace of digital adoption. Moreover, Interviewee J asserts that the lack of standardisation across all the various software and the degree of their use, poses a barrier and as a result, this deters organisations from utilising digital technologies.

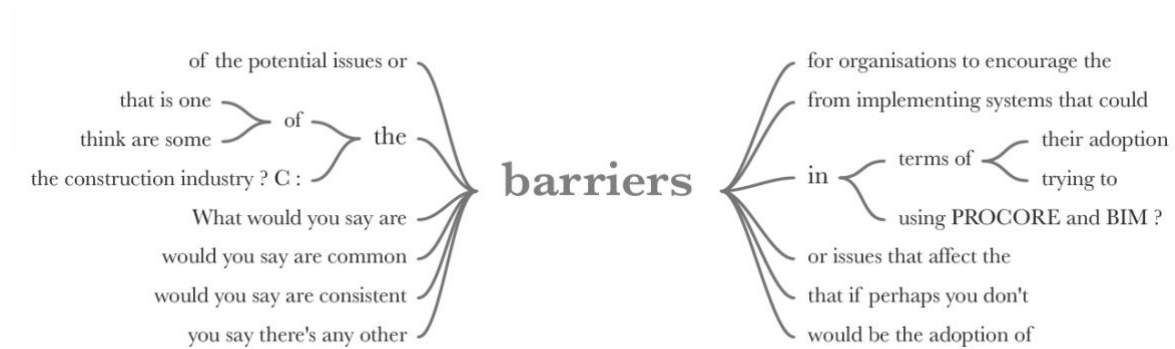


Figure 6. 7: Barriers to digitalising in the South African construction industry (Word Tree – Nvivo15)

6.6 Chapter Summary

This chapter presented the demographic composition of the Interviewees and further, reported the position, years of industry experience as well as the values of the projects they embarked on. Further to that, the chapter systematically extracted common themes expressed by the interviewees. Moreover, these themes are discussed in corroboration or contravention set as a premise across interrogated literature. The expressed and discussed themes are the presentation of the technologies commonly used, perception of the benefits of the digital technologies, legal implications of digitising, training and skill, perceived threats to digitising, health and safety, cost implications, vocational uncertainty, industry readiness and barriers to digitising in the south African construction industry.

CHAPTER SEVEN: DISCUSSION OF FINDINGS

7.1 Introduction

This chapter is dedicated to discussing the findings of the research. A focal point of discussion, is the merger of both the qualitative and the quantitative analysis of the findings. Furthermore, the findings of these results are intrinsically focussed on identifying congruency or incongruent scrutiny across the two methods of analysis. Notwithstanding that, another optic through which these findings are discussed, is perched on the already conducted studies which in part or whole, discusses and assesses the significance of digital technologies on the project productivity in the South African construction industry. In order to ensure that there is consistency in the discussion of the findings, the research objectives detailed in chapter one is used as a framework of approaching both arch and systematically establishing the distilling findings into relevant and significant discussion. Another form of compartmentalising the findings in order to draw conclusion, is the designed conceptual framework for this study which is represented in Figure 2.3. As a result, the findings are interrogated with this thinking process as a mechanic of analysis. Incumbent to the research, is the need to understand why the results occurred. Two primary reasons as stated in the methodology chapter, the study received 92 valid responses though the quantitative component and 11 interviews. This exposed the study to fewer than expected respondents and saturation of data across the two data collection methods respectfully. The discussion is based on this premise.

7.2 Research Objective 1: Identify and assess the digital technologies adopted and implemented by construction organisations in South Africa.

Through the data analysis, a poignant point of departure was to assess the familiarity and exposure of the various digital tools that professionals in the construction industry have exposure to. Table 5.3 presented the findings weighed with both standard deviations, RII values and rank. The findings suggest that mobile devices (smart and handheld devices) (DT13) are the highly ranked digital tool used in the industry. This finding is corroborated by both Interviewee I. Furthermore, this finding is posited by Shojaei and Burgess (2022) and Berlak *et al.* (2021) in asserting that an integrated connection of software to digital tools aid in the accessibility of both documentation and critical components of a project. A plethora of reasons can be attributed to this but the ease of acquisition of these devices is paramount. Additionally

smart devices have evolved significantly over the years and thus making them an easily accessible tool. The integration of these systems is further corroborated by Interviewee I and Interviewee G signify a critical merger of the happenings on construction projects with the necessary software that allows one to be able to assess and monitor progress without expending much energy or resources. Furthermore, depending on the complexity of an activity on site, these can additionally afford the entire project team to be able to amalgamate resources, time and effort to mitigate any disruptor of occurrence which may deter the project from being completed according to specifications as per respondent A's assertion. It further follows that from a communication perspective and timeous turnaround period; these mobile devices can bypass a complicated and arduous process and speedily resolve any dispute in affording all the participants an immediate resolution. Notwithstanding that, it is no coincidence that the second highly rated form of digital tool is ICT systems. Wang *et al.* (2020) posits that for an effective and smooth coordination of a project, clear and transparent communication is paramount. As a result, ICT affords this as a system integrated to computers, common software usage and mobile devices. This denotes that the South African construction industry is well versed on the integral role ICTs affect project productivity. In not so many words, Interviewee J reiterates the inconsistencies in software usage which can potentially affect the productivity of a project. Furthermore, they identified the financial and time wastage that can ensue throughout instances where there is incongruence between the differences in software being used for different sections of the project. This point is additionally hypothesized by Li *et al.* (2022) in that construction projects hardly achieve their milestones if there is no connectedness across the various tools (software) being used on a project. This phenomenon is mostly evidenced at the inception stage wherein drawings are compiled, and elements are quantified for cost. As a result, ICTs have the same effect in how they impact project productivity in South Africa (Wang *et al.*, 2020; Li *et al.*, 2022).

The third rated digital tool in South Africa is IoT. As the survey was sent throughout cidb grade companies in the categories Grade 4 – 7, this finding presents an irregular analysis as the findings further elucidate its significance with regards to aptitude and skills acquired in its usage as evidenced in Table 5.3 (R = 3). This finding contradicts Maqbool *et al.* (2023)'s assertion that the construction industry is not in a position to digitalise on a grand scale and convert all its operations digitally thus IoT becomes skill centred tool needing both the uptake from an organisation (Papulová *et al.*, 2022) and worker's willingness to learn and operate the

software (Berlak *et al.*, 2021; Demirkesen and Tezel, 2022; Smidt and Jokonya, 2022). A significant proportion of construction activities are conducted and carried out by the physical labour and specifically for South Africa, this characteristic aid in the enhancement of employment opportunities and reduction of the unemployment rate (Barbosa, Woetzel, Mischke, *et al.*, 2017; Omotayo *et al.*, 2024). Furthermore, both Interviewee F and Interviewee K posits that the industry has invested significantly in digital resources to advance productivity and train workers to acquire skills to minimise cost and optimize cost. This additionally means that in as much as productivity has been lagging as per Barbosa, Woetzel and Mischke (2017), there is a great appreciation for innovation. BIM is ranked the fourth most utilised digital tool as per the analysis. This finding is inter alia posited by Mahajan (2021) and Nassereddine *et al.* (2022). Additionally, it can be observed from Interviewees A - K that this system is commonly used in the South African construction industry.

BIM is revered for its capabilities to superimpose engineers drawings and layer them on top of each other in order to identify design clashes, missing units (such as openings, piers, bases, windows and doors) and generate a cost at a much faster rate than the traditional methods used (Maskuriy *et al.*, 2019; Wang *et al.*, 2020; Nassereddine *et al.*, 2022; Papulová *et al.*, 2022). This implies that for a coherent, transparent and quick generation of a master drawing, BIM is a software that predominantly designated to offer this function. As can be concluded from the observed findings, it is widely used in the South African construction industry. Interviewee H further mentioned that they use BIM in its standard manner (standard version) amidst the availability of an advanced version, BIM-360. They cited cost to acquire licences for advanced version as an impediment in as much as planning and cost management of a project is made easier with the BIM-360 version. This further corroborates the assertion by Berlak *et al.* (2021) that across different ties of a project development, BIM plays a crucial role in monitoring progress of both the financial and time components of a project (Loraine and Williams, 2000; Demirkesen and Tezel, 2022; van Wyk *et al.*, 2024b). As a result, the findings of this study are congruent with studies which predates it. WBPM is ranked fifth in the list of technologies consistently utilised and have greater familiarity across the construction industry. This posits no contradiction according to the findings by (Maskuriy *et al.*, 2019). As a subset of what BIM does, WBPM does a more integrate and micro breakdown of activities performed on site so as to draw a work program (Ifeoma *et al.*, 2021). This software is an amalgamation of advanced work breakdown systems such as MS Projects, Primavera and CCs as purported by Interviewee

A and Interviewee D. WBPM's functionality comprises three fundamental components which the success of a project is contingent upon. These are cost integration analysis and model cost, estimation component and contingency matrices (Maskuriy *et al.*, 2019; Ifeoma *et al.*, 2021). These features advance and allow a project manager to oversee multiple projects at once, irrespective of the scale of the size of the construction project. WBPM package is significantly used in the South African construction industry and as can be deduced from the findings of this study. Interviewee D further purported that they utilised WBPM on their project which had a contract value of over R1 billion.

The analysis further revealed that Digital Twins (DT7), Blue Beam software (DT14) and Production Robots (DT18) are the three least ranked digital tools. Interviewee D stated that the South African industry can digitalise, however when it comes to highly advanced digital tools and software, there is an aversion and dearth of skill and production capability. One of the contentions across evaluated literature as per Franklin (2024), is that the level of education, particularly STEM, can be the main contributor to the lack of sophisticated application of digital tools necessary for the advancement of the economy and subsequently, the construction industry. Furthermore, it is very important to be cognisant of the fact that the construction industry comprises both skilled and a significant portion of unskilled labourers (cidb, 2017; StatsSA, 2021; 2022). To expand more on this, unskilled labour can be trained to acquire to acquire proficiency (Interviewee A). However, operating highly advanced technical equipment, is a different paradigm which requires specialised knowledge and skill. This further incite the sparse exposure and practical application of such tools in the South African construction industry, especially if they are not always in circulation and use. This finding delineates the progression pathways significant to both exposure and application of high-tech digital tools such as digital twin technology, AI, VR and robotics when used in the construction industry (Maskuriy *et al.*, 2019; Wang *et al.*, 2020; Agenbag and Amoah, 2021).

7.3 Research Objective 2: Determine the levels of skills, knowledge, and experience required of stakeholders in the use of digital technologies on construction projects.

The evaluation of the third hypothesis (H3) of the study sought to interrogate the claim that skill, knowledge and familiarity with digital technologies have a statistically significant relationship to project performance. The hypothesis hinges on the assertion postulated by

(Aghimien *et al.*, 2021), (Berlak *et al.*, 2021) and (Siddiqui, 2022) in drawing the relationship between level of education to the probability of increased project performance. The analysis reveals that the relationship between digital technologies, as a disruptor (moderator), and the Skills_Knowledge_Experience, as well as Productivity, yields statistically insignificant results. As can be observed from Figure 5.7, the path coefficient of 0,812 is observed, which exceeds the commonly accepted threshold of 0.05, suggesting no significant relationship at the 95% confidence level. Similarly, the relationship between Skills_Knowledge_Experience and Productivity also shows a p-value of -0,041, further supporting the lack of a statistically significant correlation. These findings are aligned with the assertion made by Interviewee H in positing that, in some instances, the implementation and use of digital technologies largely rely on the organisation's propensity to implement and train the staff cohort in how these technologies work. Training and equipping top, middle and lower management on the use of digital technologies is an enhanced proposition to measure if the team can effectively utilise the said tools. These findings provide critical insight into the absence of moderating effects of digital technologies on the relationship between skills, knowledge, experience, and productivity in the given context. This observation provides a stern suggestion that the expected disruption effect of digital technologies (D1 – D18) does not yield any measurable influence on either variable at the specified confidence level. Therefore, the null hypothesis (H3) is not rejected based on this evidence, meaning the hypothesis holds. This further posits the assertion by Smidt and Jokonya (2022) and Berger (2016) in that training and levels of acquiring the necessary technical skill to utilise digital technologies can be acquired on need or exposure to the technology.

7.4 Research Objective 3: Establish the productivity standards of construction organisations on key aspects of construction projects.

The third objective of the research was to establish how construction organisations determine what constitutes construction productivity. This was further conducted with the inquiry of observing how these constructs of determination affect the structural model fit. Table 5.15 was able to achieve this on an individualistic perspective. The observed findings were that the top five constructs perceived to be the main determinants were IM8 (MIS = 0,822), IM7 (MIS = 0,804), IM9 (MIS = 0,783), IM3 (MIS = 0, 776), and IM2 (MIS = 0,730). The three least ranked determinants were IM4 (MIS = 0,717), IM1 (MIS = 0,661) and IM5 (MIS = 0,652). This is an indication that various organisations prefer to determine productivity in varying methods. This

is further elucidated by Table 5.9, which assessed the matrix of productivity determinants extracted from literature. However, these matrices do not vary significantly from those used in Table 5.15 as these amalgamated theoretical constructs and practical constructs. Furthermore, Figure 5.3 shows a further statistically significant path coefficient between the constructs and digital technologies. Across all the constructs, a statistically significant relationship was observed with a $p\text{-value} = 0,000$). This was further corroborated by the observed statistically positive path coefficients of IM1 (0,743), IM2 (0,873), IM3 (0,857), IM4 (0,803), IM5 (0,783), IM6 (0,868), IM7 (0,831), and IM8 (0,858). IM9 was removed for this model iteration as the construct had a VIF value exceeding 5.

This further reiterates the improvement outcomes of the extend the use of DTs can have on the overall project performance. Interviewee G validated this observation in positing that in the amount of investment in digital technologies (especially software) in their organisation, there has been an evidenced improvement in the clarity of communication, data and information transfer has improved and productivity and morale on construction sites has been improved. This is further anchored by both Interviewee C and Interviewee H when they reported that within the health and safety prospect of a project, a significant reduction in incidents and accidents has been observed. This further reduces the time it would ordinarily take for a construction site to be opened in the event that an accident is reported and being investigated. Subsequent to that, with the use of a digital permit system, a contractor is able to explicitly communicate that a dangerous activity is to be carried out on site. Through which stringent and robust adherence to health and safety (PPE) is paramount and that allows everyone to be observant on sit through that exercise.

7.5 Research Objective 4: Establish the impact of the digital technologies adopted on construction productivity.

In the interrogation and full analysis of the effect DTs have on project productivity, two models were generated and assessed alongside the observed results in validating or refuting the observed effects. It emerged that the two generated models used to test and analyse H1, reported the same results and thus not conflicting each other. To reiterate the findings of the models, Figure 5.3 demonstrated a positive statistically significant path coefficient of 0,646 indicating that higher levels of digital technology adoption are associated with measurable improvements in project performance. Furthermore, the statistical significance of this structural

path was assessed using bootstrapping and yielding a p-value of 0.000 within the sampled construction projects. The findings in employing both these parameters to assess the impact DTs have on project productivity acutely corroborate the assertions by Agenbag and Amoah (2021) and Aghimien *et al.* (2021) in positing that one of the main moderators necessary in the construction industry is the integration of digital technologies and adopting them in project execution. Additionally, McNamara and Sepasgozar (2021) expansively details various forms of digital innovations that can supplement and advance the production processes of a construction project and improve profitability. In revising Park (2006)'s assertion that the variance in the estimated and observed levels of project productivity is a great indicator of either a loss or improvement of performance, these emergence of the strong relation between DTs and performance can mitigate this and ensure that the loss is significantly minimised. This was further posited to be a new and modern directive that the construction industry ought to venture into, particularly given the fast pace of digital disruption observed across other sectors. Notwithstanding that, Interviewee J postulate that one of the greatest deterrents in the improvement of productivity and project performance, is the lack of standardised and well acquittance of innovation and how this affects the daily operations of a project. However, it stands to be noted that rolling out the digital mandate without valid and well interrogated methodologies of use, can also pose a great threat to the industry at large and subsequently permits the countereffect impact. Moreover, two significant project matrices (cost and time) which polarises the project productivity, can be controlled and managed according to digital adoption and further controlling the project on a micro (setting out, establishment of site and demarcating the site), mezzo (applying for construction permits, registering the project with the municipalities and obtaining wayleave permits) as well as the macro level (life-cycle operation of a project and income generating engine proponent of a projects). All these can be regulated and controlled with a clear and decisive selection of a technological tool, adequate skill of operation and controlled integration in the project endeavour.

In corroborating this hypothesis and findings, a separate evaluation was conducted using the Kruskal-Wallis test and evaluating all the DTs and their correlation to project productivity using a confidence interval of 95% and applying a 5% margin of error (p-value). These results are presented in Table 5.40 using provincial locations as the dependent variable. The analysis further revealed that across eighteen DTs, only four (4) evidenced a statistically insignificant relation against project performance. The variability in these DTs (DT4, DT7, DT11 and DT12) can be attributed multiple reasons and exposure of digital technologies being one of them.

Furthermore, (Aghimien *et al.*, 2021) postulated that in some organisation, the attitude towards digitalising is conservative due to lack of skill and potential job loss across the staff component. This they purport is based on the organisation's objective of largely focusing on interest that innovation. Additionally, depending on the size and financial fluidity of some organisations, digitalising may prove to be more a liability than a benefit. Notwithstanding that, respondent Interviewee I highlighted the differences in the kinds of systems and software that organisations use. Additionally, this variance can give some organisations the impression that they need to have a host of licences for this software, and subsequently, putting them at risk of spending more on resources that may be obsolete if not uniformly utilised. Following that, Figure 5.41 embarked on reiterating the same test, however, using general building (GB) as the independent variable. DT7, DT10, DT17 and DT18 emerged as having a statistically insignificant relationship. The core rationale behind this variance can be attributed to the fact that in general building, there is an endemic level of fragmentation (Riazi, 2016) which evidenced a propensity of fragmentation among professionals operating in silos format. This in addition to exposure and propensity of use, can be attributing factors to this. Lastly, Figure 5.42 followed the same iteration with CE (Civil Engineering) as an independent variable and only had DT3 reporting a statistically insignificant relationship.

In summary, the PLS-SEM analysis presented in Figures 5.2 and 5.3 provides statistically rigorous evidence that the adoption of digital technologies constitutes a significant predictor of project performance. The standardised path coefficient of 0.646, the highly significant p-value of 0.000, and the adjusted R^2 of 0.467 collectively substantiate the conclusion that digital transformation strategies contribute meaningfully to improved construction project outcomes. Furthermore, the Kruskal-Wallis validation further corroborates the findings. This reinforces the strategic imperative for construction industry stakeholders across public and private sectors to integrate digital technologies as a key moderator for performance enhancement.

7.6 Research Objective 5: Evaluate the gap in productivity between the traditional approach and the adoption of digital technologies.

In light of the significant advances that digitalisation has had on project productivity, an examination of how this is perceived is necessary. However, to fully assess the perception of risks reported, these external factors must be assessed across the three clusters of environmental, organisational/construction firm and technical factors. This is conducted in this

dynamic, so as to observe the kind of relationship exists when digital technologies moderate the impact of external factors.

7.6.1 Environmental Risk

Figure 5.4 presents a crucial relationship between Environmental Factors and Project Performance, as indicated by the path coefficient of -0.159 and a p-value of 0.195. This negative path coefficient suggests that as the influence of Environmental Factors increases, Productivity decreases, implying an inverse relationship between the two variables. This assertion is validated by Lefoka and Windapo (2020). A path coefficient of -0.159 is relatively strong, indicating that Environmental Factors significantly affect productivity in the context of this analysis. However, that impact is not in a desired direction. This observed analysis suggests that environmental factors such as inclement weather (rain/cold/heat) (R = 1), delays in the delivery of material (R = 2), unexpected site ground conditions (R = 3), poor site supervision (R = 4) and site location (R = 5) could potentially impede the success of a construction project and subsequently, the profitability of a project. However, it is observed that the VIF values are all within the accepted limits, indicating that these constructs are not closely related. This further indicates that the constructs are valid (Table 5.24). Additionally, Table 5.26 further purports that the constructs are distinct.

Environmental factors could encompass an array of components and variables. This further means that each project is unilaterally faced with factors that specifically affect its progress and productivity. Additionally, the effect observed can be either negative or positive. A broad range of elements, including economic conditions, political stability, environmental regulations, and societal trends some of the variables that affect project profitability, especially when assessed according to the contract under which a development is carried out. In light of this hypothesis, when digital technologies are introduced as a potential moderator, the analytical outcome changes notably (Digital Technologies x Environmental_Factors - >Productivity). The reported path coefficient of 0.138 is observed which indicates a weak and relationship between the inclusion of digital technologies and the dependent construct under investigation (project performance). Critically evaluating this observation, it can be deduced that the implementation and/or adoption of digital technologies exerts only a slight influence on the outcome variable. More importantly, the accompanying p-value of 0.209 far exceeds the conventional significance threshold of 0.05, signifying that this observed relationship lacks statistical significance. Not negating that, one must explore further why this component of

external factors yields such insignificance. Some of the reasons this could be attributed to is that the exposure and use of digital technologies is largely applied through the design stage of a construction project. Additionally, large and tangible digital robotics are not used in the South African construction industry and thus generalisability that the construction industry will benefit from digitalisation, cannot be used as a uniform assertion.

A further analysis that validates this finding was generated with the iteration of the SPSS hypothesis testing tools. The validation of this hypothesis when Kruskal-Wallis was used evidenced a non-contradicting result when environmental factors were evaluated according to location in south Africa (Provinces), GB or civil engineering firms on the cidb registry. A statistically significant relationship is not observed. These further asserts that environmental factors when moderated with digital tools, have no capability to significantly impact project performance.

7.6.2 Organisational/Firm Factor Risks

In analysing the structural linkage between organisational or firm-specific factors and overall project performance, the PLS-SEM results indicate a path coefficient of -0.276 with a p-value of 0.233 . The analysis concluded that there is a slight negative association between measured variables and their association with productivity. This relationship implies that a weak inverse relationship is observed. Furthermore, the observed p-value further demonstrated that a statistically significant relationship is not observed, where it is evident that the p-value is greater than $0,05$ ($p = 0,233$). Furthermore, Interviewee H stipulated that utilising digital tools, the training and upskilling of the workers is an activity that, in the long term, evidence the propensity of an organisation's comfortability and advancement of digitising. Similarly, the VIF values expressed in Table 5.28 indicate that the variables are not closely related, with the Fornell-Larcker indicating that the constructs are distinct.

The elevated p-value underscores an absence of statistical support for any moderating effect of digital technologies on Organisational/Firm Factors. These findings suggest that introducing digital technologies as a mediating factor in the evaluation of how organisational/firm factors impact project productivity, evidences a statistically insignificant correlation or relationship.

However, in validating this cluster of organisational factors and its impact on project performance, Kruskal-Wallis evidenced that only OC9 (Table 5.43) depicts a statistically

significant relationship. This is both elucidated by Seadon and Tookey (2019) and Jarkas (2015) in positing that changes in VAT and inflation has the ability to increase material costs and as a result, this can negatively affect the organisation. Furthermore, this effect can ripple through an organisation as the adverse effect where organisations invest less in new digital tools. This statistically significant relationship observed with OC9 is only observed when organisational/firm factors are evaluated against project productivity using geographical location (provinces) as the independent categorisation.

7.6.3 Technical Risks

The last proponent of the external factors is the technical factors envisaged to impact project productivity. Table 5.20 provides a more detailed interpretation of the relationship between technical factors and overall productivity. The achieved analysis evidenced that when technical factors are examined in isolation towards their impact on productivity, the path coefficient obtained is -0.245. Additionally, the corresponding p-value observed was 0.234. As per the standard requisite postulated by Hair *et al.* (2019) and Usakli and Rasoolimanesh (2023), the observed indicates that an extremely weak and non-significant association is evident. A further interpretation of these findings indicates that variations in the identified technical factors outlay an extremely minimal to no significant impact on project performance.

However, in order to assess the probability of these findings yielding any different outcome, the introduction of digitalisation (or digital technologies) is implemented as a moderator. An iteration of this model was conducted, and the moderating effect was tested through the interaction constructs (Digital Technologies $\times$ Technical Factors $\rightarrow$ Productivity). This yielded a path coefficient of -0.193 and a p-value of 0.419. The analysed literature (Aghimien *et al.*, 2021) does corroborate these findings in that the lack of statistical significance across the technical factors is strongly anchored in the training and levels of familiarity with the use of digital technologies. Additionally, due to the fact that the margin of digital utilisation in the construction industry is very low, measuring the actual parameter of this interaction cannot be achieved with absolute certainty. Furthermore, the variance in the forms of digital tools used gives ambiguity with regard to ascertaining clear and measurable levels of impact (Leviäkangas *et al.*, 2017; Agenbag and Amoah, 2021).

Table 5.44 presented the analysis of the hypothesis validation, and it was observed that only T7 (complexity of the project) and T11 (change orders from the designers/consultants)

substantiated a statistically significant correlation when geographical location is used as a dependent categorisation. Central to the development of any construction project, the proficiency and skill of all professionals to understand the complexity of the project is paramount. This ensures that at any given point, aspects of the project that command significant attention are afforded. This further means that should the desired level of understanding regarding the program design, material dispatch, and labour procurement be absent, project productivity will decline as upheld by Zhong *et al.* (2022). Furthermore, consistent changes in the programme, designs can significantly affect project performance. This is more so in the event that the turnaround time is arduous and lengthy.

7.7 Research Objective 6: Formulate models for assessing the impacts of adopted digital technologies on construction productivity.

Based on the discussions of the study findings discussed under Research Objective 1 – Research Objective 5, the study incorporates all the findings to develop a strategic digital framework, this is represented by Figure 7.1.

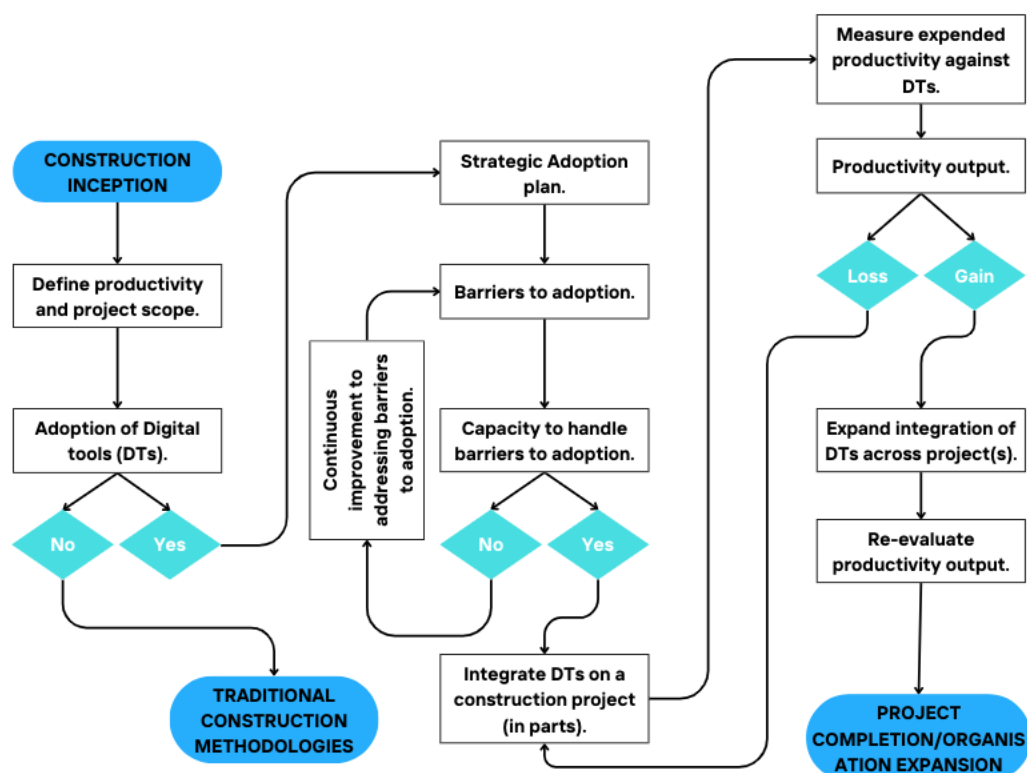


Figure 7. 1: Conceptualised Digital Framework for Productivity optimisation on construction projects.

As postulated, the determination of what constitutes productivity is imperative for any construction project (Park, 2006; Martin, 2021). This is to align the project objective and measure that against what is being expended on site. Furthermore, this is to ascertain that there is no unaccounted loss which negatively affects the performance of a project. It was determined that DTs are significant in the improvement of productivity, and in the event that an organisation chooses to not adopt DTs, traditional construction methodologies are implemented. This is attributed to multiple factors, but financial capability is considered the case, especially with cidb organisations below Grade 4 (cidb, 2022). The synthesis of the strategy begins at the point an organisation adopts some form of digital tools. It is at this juncture that construction managers, developers, planners, engineers, cost engineers, and quantity surveyors contrive an expansive and elaborate development operational strategy.

This strategy is informed by the various expertise the professional teams have and their competencies towards developing the project according to the specifications and within cost. This strategy can be specific to a project or an organisation. The next phase of the strategy is to identify eminent barriers to digital adoption. As Hypothesis two posited that external factors are not statistically significant, their omission in this strategic framework is supported. The identifies barriers were lack of investment, legislative complexity, lack of skills and cybersecurity concerns. Across these barriers, the proposed framework moves to an additional step which interrogates the capacity of the stakeholders (organisation) to address these in two parts. In the event that it is not possible to address these barriers, the project goes into a continuous loop to better improve their capacity. This can be done in the form of training, troubleshooting, trial and error as well as significant confidence from investors based on the output produced. The second part is that, if the barriers are addressed, a selection of DTs can be integrated on a project and as a result, commence the development process.

However, the crucial part in this strategic framework is to measure the variable determined to represent productivity of a project against the selected DT. This determines the profitability (gain) or loss in however the matrix yields as an output. Following which, if it is reported that gains have been observed, the construction project can leverage on that and expand the utility of DTs by employing more or expanding their use on the next project if it is an organisation. As a result, this can also afford the users of the strategy to re-evaluate productivity matrices and use multiple to simulate disruptive innovation theory and configuration theory for an

organised and expanding system (Dan and Chieh, 2008; Mikalef *et al.*, 2015). The adverse which is a loss presents an opportunity to the users of the strategy in that adoption of DTs can be done in parts and at a pace the user is able to quantify and acutely define productivity for a desired output. This strategy is a basis through which a larger and more complex iterations can be computed. This is based on the data available to this study and the findings.

7.8 Chapter Summary

This chapter discussed the findings of the study aggregated across questionnaires and interviews conducted. These findings were theoretically superimposed on the existing literature to elicit common themes and assess the gaps in this field of study for later interrogation. Innovation and specifically, digitalising the construction activities and practices, is an unfamiliar territory for the industry. Notwithstanding that, a need for this practice to be carried out is informed by the fraternity's need to improve project performance, upskill the labour component on construction projects and evade the lagging concern that sees the industry not improving. This chapter discussed in detail the levels of expertise and skill required in the use of software and physical digital tools for the betterment of the construction endeavour. From an economic and cost component, digital tools that are already in circulation are further discussed and probed for their benefit of use. This is further reinforced by the perceptions of the interviews conducted, particularly with the developers, users and heads of organisations. The discussions of the findings did not deviate far from the already existing literature. However, literature that delved into assessing the third dimension (external factors) was found to be significantly absent, and this study further found its findings enchanting a different territory in the field of digital interrogation and adoption amidst dynamic environments. Additionally, the effects of barriers to implementation were critically assessed and evaluated against enablers to implement. The latter was found to weigh significantly to the former. This further necessitates the engagement of industry, digital entrepreneurs, legislative bodies and government enterprises to amalgamate with the objective to minimise this and promote digital innovation. Lastly, a Strategic Digital Framework for Productivity optimisation was developed which encapsulate all the findings of the Research Objectives and the hypotheses.

CHAPTER EIGHT: CONCLUSION AND RECOMMENDATIONS

8.1 Introduction

This chapter presents an integrated synthesis of the research findings derived from both the quantitative data collected from respondents and the qualitative insights obtained through interviews. It evaluates the extent to which the study's objectives, outlined in the preceding chapter and used to guide the investigation, have been achieved. The chapter further discusses conclusions and recommendations relevant to higher education and training, with particular emphasis on STEM disciplines, higher learning institutions, pedagogical practices, and the broader construction industry. In addition, potential directions for future research are identified. The chapter concludes with a critical reflection on the study's processes, findings, and overall contributions.

8.2 Summary of Research Findings

An extant literature review overarches this study in that through this examination, polarisation of well researched digital techniques and their individualistic impact on project productivity was well presented. However, these were further researched across different contexts and economies across the first world. This allowed the study to contrive an encompassing question this study would explore which is stated as: *How does the adoption and implementation of digitalisation (innovative technology) impact the level of construction productivity in advancing project success on projects in South Africa?* A mixed-method research approach was used in exploring the research question and subsidiary questions. A research questionnaire was distributed across contractors registered on the cidb registry, and 92 valid responses were recorded after receiving 411 responses. These contractors are positioned across the nine (9) South African provinces by either job designation or position in the affiliate organisation. Three hypotheses were developed and were tested using the statistical analyses. These were PLS-SEM and SMPSS. Furthermore, semi-structured interviews were developed through the same rigour and conducted across 11 interviewees who are positioned across South Africa. These were conducted through Microsoft Teams platform and some through face to face.

8.3 Research Objective 1: Identify and assess the digital technologies adopted and implemented by construction organisations in South Africa.

This objective was achieved through three methods. The first approach that aided in addressing the objective was extant literature review. This method used specific key words such as digitalisation, innovation in the construction industry, adoption of technology, software used in the construction industry and benefits of digitising construction projects. Various forms of digital technologies were observed and through cross referencing, the study establishes eighteen (18) different forms of digital technologies. In the second approach, these were integrated in the research instrument (questionnaire) sent to respondents and the main five digital technologies were identified in the South African industry. These are mobile devices (smart and handheld devices), information and communication technology (ICT), Internet of Things (IoT), Building Information Software (BIM) and Web Based Project Management (WBPM). The third approach were those reported by interviewees.

8.4 Research Objective 2: Determine the levels of skills, knowledge, and experience required of stakeholders in the use of digital technologies on construction projects.

The satisfactory approach to this objective is expressed in Table 5.5 in which the respondents expressed their proficiency in the exposure and use of the different digital technologies. Mobile devices, ICT, WBPM, IoT and cloud computing were reported as digital techniques respondents were proficient in using. Through the interviews, the same sentiment was expressed in that software-based techniques, are considered not complex to understand and thus, user-friendly. As a result, this objective was achieved.

8.5 Research Objective 3: Establish the productivity standards of construction organisations on key aspects of construction projects.

An interrogation of literature significantly aided in achieving this objective. The same method of cross-referencing of methods used across the industry, twelve methods used to assess project productivity, were established. These were included in the questionnaire sent to the respondents and the finding reported that the three most used method of project productivity are meeting

the client's requirements/satisfaction, quality – intended utility of the project, adherence to health and safety – no fatalities, completing the project within time, and completing the project within cost. These are presented in Table 5.10. These approaches varied significantly with those reported by the interviewees as experience, skill and knowledge were considered to be the matrices of measure. However, through the discussion, the objective was achieved.

8.6 Research Objective 4: Establish the impact of the digital technologies adopted on construction productivity.

This objective was achieved through the use of two statistical tests. These were PLS-SEM and SPSS. The latter was employed to validate the findings reported by PLS-SEM. A statistically significant relationship was observed which was evidenced by a p-value of 0,001. Furthermore, through the Kruskal-Wallis as a verification iteration, only four digital techniques expressed a statistically non-significant relationship. These were WBPM, Digital Twins, VR and modular construction. An argument expressed by the interviews was that a strong relationship exists between digital adoption and project performance. However, further interrogation specified that a company's financial position, experience across workers and training may differ and this can present incomparable outcome. As a result, this objective was achieved.

8.7 Research Objective 5: Evaluate the gap in productivity between the traditional approach and the adoption of digital technologies.

This objective was similar to objective 5, approached and achieved with the same statistical tools. As expressed in Figure 5,4 a statistically significant relationship does not exist between environmental factors (p-value = 0,195). Figure 5.5 also reported a statistically insignificant relationship between organisational/firm factors (p-value = 0,233) and productivity. Lastly, the same relationship was observed between technical factors (p-value = 0,234) and productivity when moderated by digital technologies. In validating these findings with Kruskal-Wallis, it emerged that across organisational/firm factors, only economic changes (change in VAT, inflation and foreign exchange rate) expressed a statistically significant factor across organisational factors. And across technical factors, only complexity of the project and change orders from the designers/consultants expressed a statistically significant correlation to digital technologies.

8.8 Research Objective 6: Formulate models for assessing the impacts of adopted digital technologies on construction productivity.

The study underscores the importance of clearly defining productivity across projects or organisations. The aggregated findings indicate that DTs are perceived to significantly enhance productivity. The proposed strategic framework developed from the findings of this study suggest that key barriers to digital adoption are limited investment, legislative complexity, skill shortages and cybersecurity concerns. Notwithstanding the exclusion of external variables, the capacity for organisations to mitigate these is paramount. Moreover, the cornerstone of this strategic framework is the continuous measurement and iteration of productivity. Additionally, the strategy reports that the yield of positive outcomes enables the expansion of DTs. Overall, the strategy provides an evidence-based, iterative foundation for scaling digital adoption and advancing productivity across construction projects. As evaluated, this proposed framework of strategy is only applicable within certain confines of the construction industry. This is informed by the quantitative lens and qualitative interrogation used to engineer the strategy. This is applicable largely during the design phase of a construction project. This is attributed to a team of professionals involved in the design of a structure, quantifying the structure and restructuring the feasibility. It is for this sentiment that in the adoption of digital tools, the feedback loop can better evidence any complicated components of the work, needing supplemental technology, the lack of understanding of the proposed new tools and efficiency of production envisaged. As a result, this is a boundary of limitation. Another limitation is the economic sustainability of an organisation and the size of the project. This strategy can be better applied and implemented in organisations or structures where an acute need of use and clearly identifies sections of the scope of works are established. This better makes the strategy more effective and applicable. Notwithstanding that, the strategy can also be applied during the construction phase of a project as it allows real time observation of productivity and increase in output. These boundaries allow an organisation to easily adopt, observe and refine the strategy as the projects are carried out.

8.9 Conclusion

According to the study's findings, it can be concluded that a significant relationship exists between digital technologies and productivity matrices used across the construction industry. The study expressed a methodological analysis of literature and asserted that productivity in the construction industry is a major concern. Amidst this, the adoption of digitalisation has

been considered to be a resolve to this concern which the study has proved. The findings further found that there are significant barriers to the adoption of digital technologies in the construction industry. These barriers are found to be organisational unwillingness to adopt digital technologies, lack of investment, lack of skills, lack of standardised legislative standards. Moreover, the study concludes that when moderating external factors with digital technologies, there is no significant relationship that exists. This was further corroborated by the respondents in reporting that skills and training is pertinent when an already existing digital tool is adopted. Furthermore, organisations are not able to measure or contrive a uniform measure of productivity, thus this uncertainty promoted unwillingness to adopt. Moreover, similar to skill, acquisition of technical skills necessary to adopt digital tools can only be reinforced once a digital tool is introduced on site. This study thus concludes that various components of a project must be integrated with digital technologies as well as adhere to legislature for a successful project with promotes productivity. In conclusion, the observed relationship between adoption of digitalisation and impact on levels of productivity, is a positive statistically significant one.

8.10 Recommendations

8.10.1 Higher Education and Learning (STEM)

Digitalisation is increasingly embedded across professional and industrial sectors, reshaping the structure, demands, and dynamics of the modern work environment. This transformation is not speculative but empirical, and it necessitates an acceptance that work systems are undergoing structural reconfiguration. Within this context, concerns have been raised regarding the positioning of foundational education, particularly within the Department of Basic Education (DBE) and its implications for the depth, rigour, and conceptual integrity of Science, Technology, Engineering and Mathematics (STEM) education. A perceived dilution in STEM standards risks undermining the long-term intellectual capital required for innovation-driven sectors, particularly in engineering and the built environment. From the perspective of both industry practice and academic instruction in construction-related disciplines, a recurring observation is the declining inclination among entrants to engage in the physically and technically demanding aspects of the profession. Evidence from qualitative interviews suggests that many new entrants do not pursue construction-related careers out of intrinsic motivation or disciplinary interest, but rather as a function of limited alternative opportunities. This misalignment between aptitude, interest, and career pathway selection is further reflected in

literature indicating that current STEM pedagogical approaches may be insufficiently fostering curiosity, problem-solving orientation, and innovation capacity among learners. In response, it is argued that STEM subjects, particularly mathematics and science, should be preserved and delivered in their conceptual depth and disciplinary integrity, especially for learners intending to progress into engineering and built environment fields. Such an approach would strengthen cognitive readiness, enhance analytical competence, and better align educational outcomes with the epistemic demands of global technological and engineering ecosystems, thereby improving South Africa's competitiveness relative to international counterparts. In parallel, the integration of applied digital tools within classroom environments is essential. The incorporation of hands-on digital applications can enhance experiential learning by enabling learners to interrogate, simulate, and practically engage with real-world industrial contexts. This form of pedagogical innovation supports deeper conceptual understanding while bridging the gap between theoretical instruction and applied practice. Furthermore, STEM education would benefit from structured platforms for learner dissemination, such as regional, provincial, and national symposia. These forums would allow learners to present and critically engage with their own experimental or design-based outputs, fostering scientific communication skills, innovation capacity, and peer-to-peer learning. Importantly, such initiatives would reinforce the interdependence of technical competence and transversal skills development.

Finally, there is a need for strengthened recruitment and qualification standards for educators within the STEM education pipeline. The effectiveness of curriculum delivery is closely linked to educator capability, subject mastery, and pedagogical depth. Misalignment in subject guidance at secondary level may inadvertently constrain learners' access to advanced study pathways and limit progression into higher education, particularly in engineering disciplines. While acknowledging broader socioeconomic constraints, it remains critical to avoid systemic educational shortcomings that may result in the loss of high-potential talent due to inadequate academic nurturing. Accordingly, this necessitates a more deliberate and sustained policy dialogue between fiscal authorities and education planning bodies within South Africa, particularly the National Treasury and the Department of Basic Education, to ensure that resource allocation, curriculum design, and long-term national development objectives are coherently aligned.

8.10.2 Engineering and Built Environment (TVET and Universities)

The project manager is a central coordinating agent in construction project delivery, bearing integrated responsibility for managing engineering teams, clients, subcontractors, and the financial performance of projects. Effective project outcomes are strongly dependent on the competence of this role in integrating multidisciplinary inputs and controlling project constraints. This study recommends the development and implementation of an integrated, practice-based academic programme within universities offering Construction Management and Quantity Surveying. The proposed curriculum should be designed to consolidate core competencies across project management, technical construction processes, contractual administration, and financial control, with a strong embedded practical component. Such a programme may address industry concerns regarding the employability gap observed in graduates lacking applied experience.

It is further recommended that the programme be designed and delivered in collaboration with experienced industry practitioners possessing extensive operational and technical expertise. This would ensure alignment between academic content and prevailing industry requirements. Given the inherently fragmented structure of the construction industry, as consistently highlighted in both literature and stakeholder interviews, this integrated educational intervention may function as a mechanism to improve coordination between academia and industry. In doing so, it can establish a structured talent pipeline that facilitates graduate recruitment and workplace readiness. In addition, a dedicated grant or funding mechanism should be established to support experiential learning opportunities. This fund would enable students to undertake structured site visits and exchange programmes, both locally, particularly to projects utilising advanced construction technologies and digital laboratories and internationally, to jurisdictions demonstrating advanced adoption of digital construction technologies.

For Technical and Vocational Education and Training (TVET) institutions, the proposed programme would complement existing craftsmanship-based training by integrating theoretical and managerial competencies. This integration would enhance the capability of TVET graduates to operate effectively within digitally enabled and technologically advanced construction environments. Conversely, university students would benefit from exposure to practical skill development, thereby strengthening their appreciation of workmanship precision

and applied construction techniques. Finally, the proposed funding mechanism could be extended to support continuing professional development initiatives for built environment practitioners in South Africa, thereby strengthening sector-wide capacity in digital construction, project delivery, and integrated management practices.

8.10.3 Construction industry

A notable paradox in construction industry research lies in the persistent reluctance of industry practitioners to actively engage with the academic and scholarly community. This challenge is further exacerbated by the reported decline in project productivity and the concurrent reduction in employment opportunities within the sector, thereby foregrounding a substantive and empirically grounded problem requiring urgent investigation and resolution. To address this disconnect, it is recommended that relevant professional and regulatory bodies, namely the Construction Industry Development Board (cidb), South African Council for the Project and Construction Management Professions (SACPCMP), Engineering Council of South Africa (ECSA), and the Association of South African Quantity Surveyors (ASAQS), formalise a memorandum of understanding (MoU). Such an agreement would facilitate structured collaboration between postgraduate researchers and industry stakeholders, thereby enabling meaningful empirical engagement and enhancing the translational value of research outputs in addressing sectoral challenges.

From a technical and operational perspective, there is a critical need to strengthen capacity development within the construction workforce, particularly through targeted upskilling and continuous professional development initiatives for both senior personnel and semi-skilled labour. Furthermore, organisational frameworks should incorporate structured training interventions that enhance employees' understanding of the influence of exogenous variables on construction planning, scheduling, and project execution. This requirement becomes particularly salient in contexts where advanced digital tools and construction technologies are deployed, necessitating a higher level of digital competency and systems integration capability across all operational tiers. In addition, established construction management standards and reference frameworks such as the Project Management Body of Knowledge (PMBOK) and Standard Method of Measurement systems, stand to benefit significantly from the outcomes of this research. While these frameworks predominantly emphasise traditional construction processes and activity-based management, they exhibit limited integration of emerging digital

technologies and digitally enabled construction methodologies. The findings of this study therefore provide a basis for the enhancement of future revisions of such guidelines, with particular emphasis on incorporating structured provisions for digitalisation, technology implementation, and data-driven construction management practices.

8.11 Area for further study

This study focused on how the adoption of digitising, impacts project performance. Subcategories which emanated from this ambit were positioned to critically assess mediation effect of digitalisation on skill & knowledge as well as external factors (environmental, organisational/firm and technical factors). It can be stated that a larger sample and more time could have elicited a different outcome, however this does not negate the value of what this finding can mean for department of education (government), higher learning institutions and industry at large. In addition to that, the study proposes following three (3) domains that a further interrogation can be explored.

- a) Conducting further research on contractors that adopted digitalisation on their projects and how this has either advanced or had their organisational morale and financial component regress. This is imperative due to the lack of comparative organisations in South Africa that have used tools such as robotics, digital twins and large-scale 3D printing.
- b) An evaluation of various barriers and how they impact specific digital technologies and tools is imperative. This will provide the research field with specific barriers which are central to the slow adoption and lack of urgency across the construction industry.
- c) A study that evaluates the readiness of the South African construction industry to fully digitise. This can be a qualitative study as from the findings of this study, unanimously, all the interviewees expressed that SA is not ready. However, a few interviewees expressed the appetite to do so.
- d) An assessment of how variances in technical factors impact the proficiency of a specific digital tool. This is an area of interest in that, this study reported that incompatibility of software posed significant barriers and thus, poor project performance.
- e) Skill acquisition in the adoption and implementation of digital technologies in the South African construction industry. This forms the basis of mapping out relevant skills and

levels of academic qualifications are necessary for decision making in the selection of a specific digital tool, and how it impacts project productivity.

8.12 Contribution to knowledge

A critical gap identified in the construction management literature is the absence of standardised and universally applicable productivity measurement matrices capable of accurately evaluating project-level performance. This limitation is evident both globally and within the South African construction industry. Despite persistent reports indicating stagnation and, in some cases, declining productivity levels over the past two decades, there remains no consolidated framework that enables consistent, project-specific productivity benchmarking across organisations and contexts. This study addresses this gap by contributing a set of structured productivity matrices designed to provide context-sensitive performance indicators tailored to individual project characteristics. These matrices extend existing knowledge by enabling construction organisations to quantitatively assess productivity relative to defined project parameters, thereby improving the precision of performance evaluation and enabling evidence-based decision-making.

Furthermore, the proposed framework supports strategic digital technology selection by aligning tool adoption with organisational capability development plans and project-specific performance objectives. This alignment enhances the integration between technology adoption strategies and human capital development, thereby improving overall project delivery efficiency and productivity outcomes. The literature further reveals a limited body of work examining the rate of digital technology adoption and the level of user proficiency within South African construction organisations. While global research extensively addresses construction digitalisation and innovation diffusion, South African studies remain fragmented and predominantly focused on Building Information Modelling (BIM) as a singular digital intervention. This study expands the scope by mapping a broader range of digital tools and evaluating their applicability, uptake, and operational value within the South African construction context. The findings provide industry practitioners with a comprehensive overview of available digital construction technologies and their potential contribution to improved project execution. Importantly, the study identifies context-specific barriers to digital adoption, including infrastructural constraints, organisational readiness limitations, and environmental variability. These insights enable construction stakeholders to incorporate

contextual risk factors into strategic planning, contractual frameworks, and operational methodologies, thereby improving risk mitigation and reducing implementation uncertainty. Additionally, the study demonstrates that external environmental factors may significantly influence the operational efficiency and reliability of digital construction tools. This finding challenges prevailing assumptions in the literature that often treat digital tools as universally transferable without contextual degradation in performance. In response, the study proposes that organisations critically evaluate digital tools not only on functional capability but also on environmental resilience and operational stability under variable site conditions. This research further highlights the importance of energy reliability in supporting digital construction systems. Given the susceptibility of construction operations to power instability in certain contexts, organisations are encouraged to consider integrating alternative and backup energy solutions to ensure uninterrupted digital tool functionality and prevent productivity disruptions. From a governance perspective, the study underscores the necessity for robust legal, regulatory, and cybersecurity frameworks to safeguard digital assets, proprietary data, and user information. As digitalisation within the construction sector remains in a developmental phase, enhanced data protection mechanisms and intellectual property safeguards are essential to ensure secure data exchange, storage integrity, and resilience against external cyber threats. These findings contribute to the growing body of knowledge on cybersecurity and digital risk management in construction environments.

In terms of human capital development, the study provides evidence supporting the integration of structured digital skills training within organisational competency frameworks. As construction methodologies evolve through increased technological integration, workforce reskilling becomes essential to ensure effective tool utilisation. The proposed findings support the embedding of digital competency development within organisational training strategies, aligned with project type, scope, and technological requirements. In summation, the study has implications for national policy and education systems, particularly in relation to the South African National Digital and Future Skills Strategy (2020). Despite its policy formulation, implementation within secondary and tertiary education systems remains limited. This study provides evidence to support accelerated curriculum alignment and skills mapping initiatives aimed at integrating construction-relevant digital competencies into formal education pathways. Such alignment is critical to fostering early-stage technological literacy and improving long-term workforce readiness within the construction industry.

REFERENCES

- Ab Hamid, M.R., Sami, W. and Sidek, M.M. (2017) Discriminant validity assessment: Use of Fornell & Larcker criterion versus HTMT criterion. In, *Journal of physics: Conference series*. IOP Publishing, Vol. 890, 012163.
- Abbasi, O., Noorzai, E., Gharouni Jafari, K. and Golabchi, M. (2020) Exploring the causes of delays in construction industry using a cause-and-effect diagram: case study for Iran. *Journal of architectural engineering*, 26(3), 05020008.
- Abowitz, D.A. and Toole, T.M. (2010) Mixed method research: Fundamental issues of design, validity, and reliability in construction research. *Journal of Construction Engineering and Management*, 136(1), 108-116.
- Adebowale, O.J. and Agumba, J.N. (2023) A meta-analysis of factors affecting labour productivity of construction SMEs in developing countries. *Journal of Engineering, Design and Technology*, 21(5), 1441-1460.
- Adebowale, O.J. and Agumba, J.N. (2024) Applications of augmented reality for construction productivity improvement: a systematic review. *Smart and Sustainable Built Environment*, 13(3), 479-495.
- Adekunle, P., Aigbavboa, C., Otasowie, K. and Adekunle, S. (2023) Benefits of robotic utilization in the prefabricated construction industry. In, *Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC31)*, 746-754.
- Adeniyi, O., Thurairajah, N. and Leo-Olagbaye, F. (2024) Rethinking digital construction: A study of BIM uptake capability in BIM infant construction industries. *Construction Innovation*, 24(2), 584-605.
- Adeoye - Olatunde, O.A. and Olenik, N.L. (2021) Research and scholarly methods: Semi - structured interviews. *Journal of the american college of clinical pharmacy*, 4(10), 1358-1367.
- Africa, S. (2020) National Digital and Future Skills Strategy. Retrieved from https://www.gov.za/sites/default/files/gcis_document/202009/43730gen513.pdf.
- Agarwal, H. and Agarwal, R. (2017) First Industrial Revolution and Second Industrial Revolution: Technological differences and the differences in banking and financing of the firms. *Saudi Journal of Humanities and Social Sciences*, 2(11), 1062-1066.
- Agarwal, R., Chandrasekaran, S. and Sridhar, M. (2016) Imagining construction's digital future. *McKinsey & Company*, 24(06), 1-13.
- Agdas, D. and Ellis, R.D. (2010) The potential of XML technology as an answer to the data interchange problems of the construction industry. *Construction Management and Economics*, 28(7), 737-746.
- Agenbag, H. and Amoah, C. (2021) The impact of modern construction technology on the workforce in the construction industry. In, *IOP Conference Series: Earth and Environmental Science*. IOP Publishing, Vol. 654, 012001.
- Aghimien, D., Aigbavboa, C., Oke, A. and Koloko, N. (2018a) December. Digitalisation in construction industry: Construction professionals perspective. In *Proceedings of the Fourth Australasia and South-East Asia Structural Engineering and Construction Conference*, Brisbane, Australia., 3-5.
- Aghimien, D., Aigbavboa, C., Oke, A. and Koloko, N. (2018b) Digitalisation in construction industry: Construction professionals perspective. In, *Proceedings of the Fourth Australasia and South-East Asia Structural Engineering and Construction Conference*, Brisbane, Australia, 3-5.
- Aghimien, D., Aigbavboa, C., Meno, T. and Ikuabe, M. (2021) Unravelling the risks of construction digitalisation in developing countries. *Construction Innovation*.

- Aghimien, D., Aigbavboa, C., Oke, A., Thwala, W. and Moripe, P. (2022) Digitalization of construction organisations—a case for digital partnering. *International Journal of Construction Management*, 22(10), 1950-1959.
- Aigbavboa, C. and Kissi, E. (2025) *Digital Management of Construction Costs*. Elsevier.
- Akinradewo, O., Aigbavboa, C., Adekunle, S., Ebekozi, A. and Ebiloma, D. (2024) Impediments to the Implementation of Building Information Modelling for Project Planning. In, *International Conference on Construction in the 21st Century*. East Carolina University.
- Al Omari, R., Sweis, G., Abu-Khader, W. and Sweis, R. (2023) Barriers to the Adoption of Digitalization in the Construction Industry: Perspectives of Owners, Consultants, and Contractors. *Construction Economics & Building*, 23.
- Alaloul, W.S., Liew, M., Zawawi, N.A.W.A. and Kennedy, I.B. (2020) Industrial Revolution 4.0 in the construction industry: Challenges and opportunities for stakeholders. *Ain shams engineering journal*, 11(1), 225-230.
- Aleksandrova, A., Truntsevsky, Y. and Polutova, M. (2022) Digitalization and its impact on economic growth. *Brazilian Journal of Political Economy*, 42(2), 424-441.
- Alinaitwe, H., Mwakali, J. and Hansson, B. (2005) Labour Productivity in the building industry. *Understanding the Construction Business and Companies in the New Millennium*, 210-220.
- Alinaitwe, H.M., Mwakali, J.A. and Hansson, B. (2007) Factors affecting the productivity of building craftsmen - Studies of Uganda. *Journal of Civil Engineering and Management*, 13(3), 169-176.
- Aliu, J. and Oke, A.E. (2023) Construction in the digital age: exploring the benefits of digital technologies. *Built Environment Project and Asset Management*, 13(3), 412-429.
- Allmon, E., Hass, C., Borcherdig, J. and Goodrum, P. (2000) US construction labor productivity trends, 1970 - 1998. *Journal of Construction Engineering and Management*, 126(2), 97-104.
- Allsop, D.B., Chelladurai, J.M., Kimball, E.R., Marks, L.D. and Hendricks, J.J. (2022) Qualitative methods with Nvivo software: A practical guide for analyzing qualitative data. *Psych*, 4(2), 142-159.
- Almamlook, R., Bzizi, M., Al-Kbisbeh, M., Ali, T. and Almajiri, E. (2020) Factors Affecting Labor Productivity in the Construction Industry. *American Journal of Environmental Science and Engineering*, 4(4), 24-30.
- Alwashah, Z., Sweis, G.J., Abu Hajar, H., Abu-Khader, W. and Sweis, R.J. (2024) Challenges to adopt digital construction technologies in the Jordanian construction industry. *Construction Innovation*.
- Andersen, O. (1997) Internationalization and market entry mode: A review of theories and conceptual frameworks. *MIR: Management International Review*, 27-42.
- Antunes, R. and Gonzalez, V. (2015) A production model for construction: A theoretical framework. *Buildings*, 5(1), 209-228.
- Arabshahi, M., Wang, D., Sun, J., Rahnamayiezekavat, P., Tang, W., Wang, Y. and Wang, X. (2021) Review on sensing technology adoption in the construction industry. *Sensors*, 21(24), 8307.
- Argyroudis, S.A., Mitoulis, S.A., Chatzi, E., Baker, J.W., Brilakis, I., Gkoumas, K., Voudoukas, M., Hynes, W., Carluccio, S. and Keou, O. (2022) Digital technologies can enhance climate resilience of critical infrastructure. *Climate Risk Management*, 35, 100387.
- Arsić, M. (2020) Impact of digitalisation on economic growth, productivity and employment. *Economic Themes*, 58(4), 431-457.

- Aruleba, K. and Jere, N. (2022) Exploring digital transforming challenges in rural areas of South Africa through a systematic review of empirical studies. *Scientific African*, 16, e01190.
- Ashton, T.S. (1997) *The industrial revolution 1760-1830*. Oxford University Press.
- Awodele, I.A., Mewomo, M.C. and Eze, E.C. (2023) Inhibitors to the adoption of building information modelling in modular construction: a case study of the Nigerian construction industry. *Journal of Construction in Developing Countries*, 28(2), 19-36.
- Ayers, S. (1997) The Application of Chaos Theory to Psychology. *Theory & Psychology*, 7(3), 373-398.
- Azman, N.S., Ramli, M.Z., Razman, R., Zawawi, M.H., Ismail, I.N. and Isa, M.R. (2019) Relative importance index (RII) in ranking of quality factors on industrialised building system (IBS) projects in Malaysia. In, *AIP Conference Proceedings*. AIP Publishing LLC, Vol. 2129, 020029.
- Baloyi, L. and Bekker, M. (2011) Causes of construction cost and time overruns: The 2010 FIFA World Cup stadia in South Africa. *Acta Structilia*, 18(1), 51-67.
- Barbosa, F., Woetzel, J. and Mischke, J. (2017) Reinventing construction: A route of higher productivity. McKinsey Global Institute.
- Barbosa, F., Woetzel, J., Mischke, J., Ribeirinho, M.J., Sridhar, M., Parsons, M., Bertram, N. and Brown, S. (2017) Reinventing Construction: A route to Higher Productivity. McKinsey Global Institute.
- Bargoni, A., Ferraris, A., Vilamová, Š. and Wan Hussain, W.M.H. (2024) Digitalisation and internationalisation in SMEs: a systematic review and research agenda. *Journal of Enterprise Information Management*, 37(5), 1418-1457.
- Barlish, K. and Sullivan, K. (2012) How to measure the benefits of BIM—A case study approach. *Automation in Construction*, 24, 149-159.
- Baruch, Y. (1999) Response rate in academic studies—A comparative analysis. *Human relations*, 52(4), 421-438.
- Berchtold, A. (2019) Treatment and reporting of item-level missing data in social science research. *International journal of social research methodology*, 22(5), 431-439.
- Berger, R. (2016) Digitization in the Construction Industry. *Think Act.*, 116.
- Berlak, J., Hafner, S. and Kuppelwieser, V., G. (2021) Digitalization's impacts on productivity: A model-based approach and evaluation in Germany's building construction industry. *Production Planning & Control*, 32(4), 335-345.
- Bienhaus, F. and Haddud, A. (2018) Procurement 4.0: factors influencing the digitisation of procurement and supply chains. *Business Process Management Journal*, 24(4), 965-984.
- Blair, J., Czaja, R.F. and Blair, E.A. (2013) *Designing surveys: A guide to decisions and procedures*. Sage publications.
- Boadu, E.F., Wang, C.C. and Sunindijo, R.Y. (2020) Characteristics of the construction industry in developing countries and its implications for health and safety: An exploratory study in Ghana. *International journal of environmental research and public health*, 17(11), 4110.
- Bonett, D.G. and Wright, T.A. (2015) Cronbach's alpha reliability: Interval estimation, hypothesis testing, and sample size planning. *Journal of Organizational Behavior*, 36(1), 3-15.
- Boulle, A., Heekes, A., Tiffin, N., Smith, M., Mutemaringa, T., Zinyakatira, N., Phelanyane, F., Pienaar, C., Buddiga, K. and Coetzee, E. (2019) Data centre profile: the provincial health data centre of the Western Cape Province, South Africa. *International Journal of Population Data Science*, 4(2).

- Bowling, A. (2005) Mode of questionnaire administration can have serious effects on data quality. *Journal of Public Health*, 27(3), 281-291.
- Brown, G.H. (1947) A comparison of sampling methods. *Journal of marketing*, 11(4), 331-337.
- Brynjolfsson, E. (1993) The productivity paradox of information technology. *Communications of the ACM*, 36(12), 66-77.
- Cahit, K.A.Y.A. (2015) Internal validity: A must in research designs. *Educational Research and Reviews*, 10(2), 111-118.
- Calantone, R.J., Griffith, D.A. and Yalcinkaya, G. (2006) An empirical examination of a technology adoption model for the context of China. *Journal of International Marketing*, 14(4), 1-27.
- Carr, L.T. (1994) The strengths and weaknesses of quantitative and qualitative research: what method for nursing? *Journal of Advanced Nursing*, 20(4), 716-721.
- Casini, M. (2021) *Construction 4.0: Advanced technology, tools and materials for the digital transformation of the construction industry*. Woodhead Publishing.
- Castagnino, S., Rothballer, C. and Gerbert, P. (2016) What's the Future of the Construction Industry. In *World Economic Forum*, 97-104.
- Chandler Jr, A.D. (1993) *The visible hand*. Harvard university press.
- Chen, X., Chang-Richards, A.Y., Yiu, T.W., Ling, F.Y.Y., Pelosi, A. and Yang, N. (2024) A multivariate regression analysis of barriers to digital technologies adoption in the construction industry. *Engineering, Construction and Architectural Management*, 31(11), 4281-4307.
- Chen, X., Chang-Richards, A.Y., Pelosi, A., Jia, Y., Shen, X., Siddiqui, M.K. and Yang, N. (2022) Implementation of technologies in the construction industry: a systematic review. *Engineering, Construction and Architectural Management*, 29(8), 3181-3209.
- Chowdhury, T., Adafin, J. and Wilkinson, S. (2019) Review of digital technologies to improve productivity of New Zealand construction industry.
- Christensen, C.M. (1997) *The Innovator's dilemma: When new technologies cause great firms to fail*. Harvard Business School Press.
- Christensen, C.M. (2015) *The innovator's dilemma: when new technologies cause great firms to fail*. Harvard Business Review Press.
- cidb (2015) *Labour & Work Conditions in the South African Construction Industry - Status and Recommendations*.
- cidb (2017) *Construction Monitor, Employment Q3*. [Online]. Available: <http://www.cidb.org.za/publications/Documents/Construction%20Monitor%20-%20October%202015.pdf> [Accessed 27 July 2017, 2017].
- cidb (2022) *Requirement for Track Record* [Online]. Available: <https://www.cidb.org.za/contractors/register-of-contractors/requirements-for-grading/>.
- Cidik, M. (2019) September. Construction productivity and digitalisation: An IT productivity paradox perspective. In *35th Annual ARCOM Conference*.
- Çıdık, M.S., Boyd, D. and Thuraijah, N. (2017) Ordering in disguise: digital integration in built-environment practices. *Building Research & Information*, 45(6), 665-680.
- Çıdık, M.S., Boyd, D. and Thuraijah, N. (2017) Ordering in disguise: digital integration in built-environment practices. *Building Research & Information*, 45(6), 665-680.
- Coates, V., Farooque, M., Klavans, R., Lapid, K., Linstone, H.A., Pistorius, C. and Porter, A.L. (2001) On the future of technological forecasting. *Technological Forecasting and Social Change*, 67(1), 1-17.
- Cochran, W.G. (1977) *Sampling techniques*. John Wiley & Sons.
- Corley, K., Bansal, P. and Yu, H. (2021) An editorial perspective on judging the quality of inductive research when the methodological straightjacket is loosened. *Strategic Organization*, 19(1), 161-175.

- Correa, S.L.M. and Santos, E.T. (2021) BIM support in the tendering phase of infrastructure projects. In, Proceedings of the 18th International Conference on Computing in Civil and Building Engineering: ICCCBE 2020. Springer, 383-392.
- Creswell, J.W. (1996) Research design. Qualitative and Quantitative Approach. Thousand Oaks: SagePublications.
- Creswell, J.W. (2009) Research methods. JW Creswell, Research design: qualitative, quantitative and mixed methods approaches, 15-17.
- Creswell, J.W. (2011) Educational Research: Planning, conducting and evaluating qualitative and quantitative research . Phi Learning Pvt. Ltd. New Delhi.
- Creswell, J.W. and Clark, V.L.P. (2017a) Designing and conducting mixed methods research. Sage publications.
- Creswell, J.W. and Clark, V.L.P. (2017b) Designing and conducting mixed methods research. Sage publications.
- Cronbach, L.J. (1951) Coefficient alpha and the internal structure of tests. Psychometrika, 16(3), 297-334.
- Curry, D.M. (2012) Practical application of chaos theory to systems engineering. Procedia Computer Science, 8(39-44).
- Dan, Y. and Chieh, H.C. (2008) A reflective review of disruptive innovation theory. In PICMET'08-2008 Portland International Conference on Management of Engineering & Technology., 402-414.
- Davis, R.N. (1999) Web-based administration of a personality questionnaire: Comparison with traditional methods. Behavior Research Methods, Instruments, & Computers., 31(4), 572-577.
- De Groen, W.P., Lenaerts, K., Bosc, R. and Paquier, F. (2017) Impact of digitalisation and the on-demand economy on labour markets and the consequences for employment and industrial relations. Final Study. CEPS Special Report, August 2017.
- Degryse, C. (2016) Digitalisation of the economy and its impact on labour markets. ETUI research paper-working paper.
- Demirkesen, S. and Tezel, A. (2022) Investigating major challenges for industry 4.0 adoption among construction companies. Engineering, Construction and Architectural Management, 29(3), 1470-1503.
- Dhakal, K. (2022) NVivo. Journal of the Medical Library Association: JMLA, 110(2), 270.
- Dixit, S., Mandal, S.N., Sawhney, A. and Singh, S. (2017) Relationship between skill development and productivity in construction sector: A literature review. International Journal of Civil Engineering and Technology, 8(8), 649-665.
- Durdyev, S. and Mbachu, J. (2011) On-site Labour Productivity of New Zealand Construction Industry: Key Constraints and Improvement Measures. Construction Economics and Building, 11(3).
- Durdyev, S. and Hosseini, M.R. (2020) Causes of delays on construction projects: a comprehensive list. International Journal of Managing Projects in Business, 13(1), 20-46.
- Ebekozien, A. and Samsurijan, M.S. (2024) Incentivisation of digital technology takers in the construction industry. Engineering, Construction and Architectural Management, 31(4), 1373-1390.
- Ebekozien, A., Uwadia, F. and Usman, D. (2015) The impact of design errors and incomplete drawings on construction project delivery in Nigeria. In, Proceedings of the Academic Conference of African Scholar Publications & Research International on Sub-Sahara African Transformation and National Development, Kaduna, Nigeria.

- El Asmar, P.G., Chalhoub, J., Ayer, S.K. and Abdallah, A.S. (2021) Contextualizing benefits and limitations reported for augmented reality in construction research. *J. Inf. Technol. Constr.*, 26, 720-738.
- Elliott-Mainwaring, H. (2021) Exploring using NVivo software to facilitate inductive coding for thematic narrative synthesis. *British Journal of Midwifery*, 29(11), 628-632.
- Emmanuel, O.A., Omoregie, A.D. and Koloko, A.C.O. (2018) Challenges of digital collaboration in the South African construction industry. In, *Proceedings of the International Conference on industrial engineering and operations management*, 6-8.
- Enshassi, A., Al - Najjar, J. and Kumaraswamy, M. (2009) Delays and cost overruns in the construction projects in the Gaza Strip. *Journal of Financial Management of Property and Construction*, 14(2), 126-151.
- Enshassi, A., Mohamed, S., Mustafa, Z.A. and Mayer, P.E. (2007) Factors Affecting Labour Productivity in Building Projects in the Gaza Strip. *Journal of Civil Engineering and Management*, 13(4), 245-254.
- Evans, J.R. and Mathur, A. (2005) The value of online surveys. *Internet research*, 15(2), 195-219.
- Fadhel, K. (2002) Positivist and hermeneutic paradigm, A critical evaluation under their structure of scientific practice. *The Sosland Journal*, 6(5), 21-28.
- Farnad, N. and Pouya, N. (2013) Dynamic modeling of labour productivity in construction projects. *International Journal of Project Management*, 31(2), 903-911.
- Fernandez-Solis, J.L. (2013) Building construction: A deterministic non-periodic flow—A case study of chaos theories in tracking production flow. *Architectural engineering and design management*, 9(1), 21-48.
- Findley, M.G., Kikuta, K. and Denly, M. (2021) External validity. *Annual review of political science.*, 24(1), 365-393.
- Fiss, P.C. (2007) A set-theoretic approach to organizational configurations. *Academy of management review*, 32(4), 1180-1198.
- Franklin, B. (2024) STEM Education in SA: academic and vocational NSTF/proSET discussion forum.
- Franklin, C. and Ballan, M. (2001) Reliability and validity in qualitative research. *Reliability and validity in qualitative research. The handbook of social work research methods.*, 4, 273-292.
- Freddi, D. (2018) Digitalisation and employment in manufacturing. *Ai & Society*, 33(3), 393-403.
- Fricker, R.D. and Schonlau, M. (2002) Advantages and disadvantages of Internet research surveys: Evidence from the literature. *Field methods*, 14(4), 347-367.
- Fugar, F.D. and Agyakwah-Baah, A.B. (2010) Delays in building construction projects in Ghana. *Construction Economics and Building*, 10(2), 103-116.
- Fusch Ph D, P.I. and Ness, L.R. (2015) Are we there yet? Data saturation in qualitative research.
- García de Soto, B., Turk, Ž., Maciel, A., Mantha, B., Georgescu, A. and Sonkor, M.S. (2022) Understanding the significance of cybersecurity in the construction industry: Survey findings. *Journal of Construction Engineering and Management*, 148(9), 04022095.
- Gephart, R.P. (2004) Qualitative research and the Academy of Management Journal.
- Giang, D.T. and Pheng, L.S. (2011) Role of construction in economic development: Review of key concepts in the past 40 years. *Habitat International*, 33(1), 118-125.
- Golafshani, N. (2003) Understanding reliability and validity in qualitative research. *The qualitative report*, 8(4), 597-606.
- Goralski, M.A. and Tan, T.K. (2020) Artificial intelligence and sustainable development. *The International Journal of Management Education*, 18(1), 100330.

- Goubran, S. (2019) On the role of construction in achieving the SDGs. *Journal of sustainability research*, 1(2).
- Gray, J. and Rumpe, B. (2015) Models for digitalization. *Software and Systems Modeling*, 14(4), 1319-1320.
- Green, B. (2015) Understanding the value of professionals and professional bodies. Chartered Institute of Building. London: Chartered Institute of Building.
- Hair, J.F., Risher, J.J., Sarstedt, M. and Ringle, C.M. (2019) When to use and how to report the results of PLS-SEM. *European business review*, 31(1), 2-24.
- Ham, N.-H., Min, K.-M., Kim, J.-H., Lee, Y.-S. and Kim, J.-J. (2008) A study on application of bim (building information modeling) to pre-design in construction project. In, 2008 Third International Conference on Convergence and Hybrid Information Technology. IEEE, Vol. 1, 42-49.
- Han, Q., Chang, J., Liu, G. and Zhang, H. (2022) The carbon emission assessment of a building with different prefabrication rates in the construction stage. *International journal of environmental research and public health*, 19(4), 2366.
- Hancock, D.R., Algozzine, B. and Lim, J.H. (2021) Doing case study research: A practical guide for beginning researchers.
- Heymann, E., Körner, K., Schneider, S. and AG, D.B. (2018) Digital infrastructure.
- Heyvaert, M., Hannes, K., Maes, B. and Onghena, P. (2013) Critical appraisal of mixed methods studies. *Journal of mixed methods research*, 7(4), 302-327.
- Hiyassat, M.A., Hiyari, M.A. and Sweis, G.J. (2016) Factors affecting construction labour productivity: a case study of Jordan. *International Journal of Construction Management*, 16(2), 138-149.
- Holt, G.D., Olomolaiye, P.O. and Harris, F.C. (1995) A review of contractor selection practice in the UK construction industry. *Building and Environment*, 30(4), 553-561.
- Hughes, R. and Thorpe, D. (2014) A review of enabling factors in construction industry in an Australian environment. *Construction Innovation*, 14(2), 210-228.
- Hwang, B.-G., Ngo, J. and Teo, J.Z.K. (2022) Challenges and strategies for the adoption of smart technologies in the construction industry: The case of Singapore. *Journal of Management in Engineering*, 38(1), 05021014.
- Ibem, E.O. and Laryea, S. (2014) Survey of digital technologies in procurement of construction projects. *Automation in Construction*, 46, 11-21.
- IDC (2020) Digital Transformation: the future of connected construction. In.
- Ifeoma, A.R., Phina, O.N., Nwanonigwe, A.G. and Uchechukwu, E.S. (2021) Digital transformation and business sustainability of telecommunication firms in Lagos State, Nigeria. *IOSR Journal of Economics and Finance (IOSR-JEF)*, 12(3), 10-15.
- Ikuabe, M., Aghimien, D., Aigbavboa, C. and Oke, A. (2020) Inhibiting factors to the adoption of digital technologies in the South African construction industry. In, *Proceedings of the 5th Research Conference of the Nigerian Institute of Quantity Surveyors (RECON 5)*, 455-461.
- Jang, H., Kim, K., Kim, J. and Kim, J. (2011) Labour productivity model for reinforced concrete construction projects. *Construction Innovation*, 11(1), 92-113.
- Jarkas, A.M. (2015) Factors influencing labour productivity in Bahrain's construction industry. *International Journal of Construction Management*, 15(1), 94-108.
- Jarkas, A.M. and Bitar, C.G. (2012) Factors Affecting Construction Labor Productivity in Kuwait. *Journal of Construction Engineering and Management*, 138(7).
- Johnson, R.B. and Onwuegbuzie, A.J. (2004) Mixed methods research: A research paradigm whose time has come. *Educational researcher*, 33(7), 14-26.

- Kadir, M.R.A., Lee, W.P., Jafaar, M.S., Sapuan, S.M. and Ali, A.A.A. (2005) Factors affecting construction labour productivity for Malaysian residential projects. *Structural Survey*, 23(1), 42-54.
- Kaming, P.F., Olomolaiye, P.O., Holt, G.D. and Harris, F.C. (1997) Factors influencing construction time and cost overruns on high-rise projects in Indonesia. *Construction Economics & Management*, 15(1), 83-94.
- Kaming, P.F., Holt, G.D., Kometa, S.T. and Olomolaiye, P.O. (1998) Severity diagnosis of productivity problems - a reliability analysis. *International Journal of Project Management*, 16(2), 107-113.
- Karatsareas, P. (2022) Semi-structured interviews. *Research methods in language attitudes*, 99.
- Karpov, V. (2010) Desecularization: A conceptual framework. *Journal of Church and State*, 52(2), 232-270.
- Kavuri, A., Soetanto, R., Goodier, C., Murguia, D. and Szczygiel, M. (2020) Scenarios for the digitalisation of the construction industry.
- Kaynak, H. (2003) The relationship between total quality management practices and their effects on firm performance. *Journal of Operations Management*, 21(4), 405-435.
- Kazaz, A. and Ulubeyli, S. (2004) A different approach to construction labour in Turkey: comparative productivity analysis. *Building and Environment*, 39, 93-100.
- Keeves, J.P. (1997) *Educational research methodology and measurement*. Cambridge: Cambridge University Press.
- Khan, A.A. and Ajmal, S. (2015) Role of Management in Motivating Labour. *Journal of Advanced Management Science*, 3(3).
- Kimberlin, C.L. and Winterstein, A.G. (2008) Validity and reliability of measurement instruments used in research. *American Journal of Health-System Pharmacy*, 65(23), 2276-2284.
- Kivunja, C. (2018) Distinguishing between theory, theoretical framework, and conceptual framework: A systematic review of lessons from the field. *International Journal of Higher Education*, 7(6), 44-53.
- Kivunja, C. and Kuyini, A.B. (2017) Understanding and Applying Research Paradigms in Educational Context. *International Journal of Higher Education*, 6(5), 26-41.
- Kong, L. and Lv, F. (2021) Application of 3D laser scanning technology in engineering field. In, *E3S Web of Conferences*. EDP Sciences, Vol. 233, 04014.
- Kongolo, M. (2024) Job creation versus job shedding and the role of SMEs in economic development: Small business, entrepreneurship, job creation, job shedding, economic development, poverty alleviation. *Review of Business and Economic Development*, 1(001).
- Kothari, C. (2004) *Research methodology: Methods and techniques*. New Age International.
- Kumar, R. (2014) *Research Methodology a step-by-step guide for beginners*. Sage publications.
- Lai, P.C. (2017) The literature review of technology adoption models and theories for the novelty technology. *JISTEM-Journal of Information Systems and Technology Management*, 14, 21-38.
- Lam, K., Lee, D. and Hu, T. (2001) Understanding the effect of the learning-forgetting phenomenon to duration of projects construction. *International Journal of Project Management*, 19(7), 411-420.
- Landes, D.S. (2003) *The Unbound Prometheus*. Cambridge Books.
- Lang, T. and Ramirez, R. (2017) Building new social capital with scenario planning. *Technological Forecasting and Social Change*, 124, 51-65.
- Lederman, N.G. and Lederman, J.S. (2015) What is a theoretical framework? A practical answer. *Journal of Science Teacher Education*, 26(7), 593-597.

- Leedy, P.D. and Ormrod, J.E. (2005) Practical research. Pearson Custom.
- Lefoka, M. and Windapo, A. (2020) An Examination of Contextual Factors that Cause Variations in Labour Productivity. In, The Construction Industry in the Fourth Industrial Revolution: Proceedings of 11th Construction Industry Development Board (CIDB) Postgraduate Research Conference 11. Springer, 355-363.
- Lefoka, M.M. (2019) An evaluation of the contextual factors that affect labour productivity in the South African Construction Industry.
- Lema, N.M. (1996) Construction labour productivity analysis and benchmarking: the case of Tanzania., Ninatubu Mboru Lema.
- Leung, M.-y., Angky, D.A., Bowen, P., Hamid, H., Humdhan, M., Khoo, S., Ling, F., Ongpeng, J., Zainordin, N. and Zhang, H. (2024) Preliminary results of a questionnaire survey on the performance of digitalized tools in the quantity surveying practices. In, PAQS 2024: Digitalization towards a Smart Nation.
- Leviäkangas, P., Paik, S.M. and Moon, S. (2017) Keeping up with the pace of digitization: The case of the Australian construction industry. *Technology in Society*, 50, 33-43.
- Li, Y., Sun, H., Li, D., Song, J. and Ding, R. (2022) Effects of digital technology adoption on sustainability performance in construction projects: The mediating role of stakeholder collaboration. *Journal of Management in Engineering*, 38(3), 04022016.
- Limna, P. (2023) The impact of NVivo in qualitative research: Perspectives from graduate students. *Journal of Applied Learning and Teaching*, 6(2), 271-282.
- Lohr, S.L. (2021) Sampling: design and analysis. Chapman and Hall/CRC.
- Lopes, J. (1998) The construction industry and macroeconomy in Sub-Saharan Africa post 1970. *Construction Management & Economics*, 16(6), 637-649.
- Lorraine, R. and Williams, I. (2000) Partnering in the social housing sector: A handbook. Thomas Telford.
- Love, P.E. (2002) Influence of project type and procurement method on rework costs in building construction projects. *Journal of Construction Engineering and Management*, 128(1), 18-29.
- Love, P.E.D., Holt, G.D., Shen, L.Y., Li, H. and Irani, Z. (2002) Using systems dynamics to better understand change and rework in construction project management systems. *International Journal of Project Management*, 20, 425-436.
- Lu, W., Lee, W.M., Xue, F. and Xu, J. (2021) Revisiting the effects of prefabrication on construction waste minimization: A quantitative study using bigger data. *Resources, conservation and recycling*, 170, 105579.
- Lu, W., Lou, J., Ababio, B.K., Zhong, R.Y., Bao, Z., Li, X. and Xue, F. (2024) Digital technologies for construction sustainability: Status quo, challenges, and future prospects. *npj Materials Sustainability*, 2(1), 10.
- Lu, X., Clements-Croome, D. and Viljanen, M. (2010) Integration of chaos theory and mathematical models in building simulation: part II: conceptual frameworks. *Automation in Construction*, 19(4), 452-457.
- Mackenzie, N. and Knipe, S. (2006) Research dilemmas: Paradigms, methods and methodology. *Issues in educational research*, 16(2), 193-205.
- Madanayake, U. and Cidik, M. (2019) The potential of digital technology to improve construction productivity. In *Proceedings of 35th Annual ARCOM Conference.*, 416-425.
- Mahajan, G. (2021) Applications of drone technology in construction industry: A study 2012-2021. *International Journal of Engineering and Advanced Technology*, 11(1), 224-239.
- Mahamid, I. (2012) Factors affecting contractor's business failure: contractors' perspective. *Engineering, Construction and Architectural Management*, 19(3), 269-285.

- Mahamid, I. (2013) Common risks affecting time overrun in road construction projects in Palestine: Contractors' perspective. *Construction Economics and Building*, 13(2), 45-53.
- Makulsawatudom, A., Emsley, M. and Sinthawanarong, K. (2004) Critical Factors Influencing Construction Productivity in Thailand. *The Journal of KMITNB*, 14(3), 1-6.
- Mallery, P. and George, D. (2005) *SPSS for Windows Step by Step: A Simple Guide and Reference 13.0 Update*. Allyn and Bacon.
- Manfreda, K.L., Bosnjak, M., Berzelak, J., Haas, I. and Vehovar, V. (2008) Web surveys versus other survey modes: A meta-analysis comparing response rates. *International Journal of Market Research*, 50(1), 79-104.
- Maqbool, R., Saiba, M.R. and Ashfaq, S. (2023) Emerging industry 4.0 and Internet of Things (IoT) technologies in the Ghanaian construction industry: sustainability, implementation challenges, and benefits. *Environmental Science and Pollution Research*, 30(13), 37076-37091.
- Marks, B. and Thomas, J. (2022) Adoption of virtual reality technology in higher education: An evaluation of five teaching semesters in a purpose-designed laboratory. *Education and information technologies*, 27(1), 1287-1305.
- Martin, J. (2021) Productivity in the construction industry, UK. An Investigation into Productivity Growth and Its Drivers for the UK Construction Industry.
- Maskuriy, R., Selamat, A., Ali, K.N., Maresova, P. and Krejcar, O. (2019) Industry 4.0 for the construction industry—how ready is the industry? *Applied Sciences*, 9(14), 2819.
- Maxwell, J.A. (2010) Using numbers in qualitative research. *Qualitative inquiry*, 16(6), 475-482.
- McNamara, A.J. and Sepasgozar, S.M. (2021) Intelligent contract adoption in the construction industry: Concept development. *Automation in Construction*, 122, 103452.
- Meintjes, I., Bowen, P. and Root, D. (2007) HIV/AIDS in the South African construction industry: understanding the HIV/AIDS discourse for a sector-specific response. *Construction Management and Economics*, 25, 255-266.
- Migiro, S.O. and Magangi, B. (2011) Mixed methods: A review of literature and the future of the new research paradigm. *African journal of business management*, 5(10), 3757-3764.
- Mikalef, P., Pateli, A., Batenburg, R.S. and Wetering, R.v.d. (2015) Purchasing alignment under multiple contingencies: a configuration theory approach. *Industrial Management & Data Systems*, 115(4), 625-645.
- Mohajan, H. (2021) Third industrial revolution brings global development.
- Mohd Naw, M.N., Baluch, N.H. and Bahaudin, A.Y. (2014) Impact of fragmentation issue in construction industry: An overview. In, *MATEC web of conferences*. EDP Sciences, Vol. 15, 01009.
- Mokyr, J. and Strotz, R.H. (1998) The second industrial revolution, 1870-1914. *Storia dell'economia Mondiale*, 21945(1), 219-245.
- Morse, J.M., Barrett, M., Mayan, M., Olson, K. and Spiers, J. (2002) Verification strategies for establishing reliability and validity in qualitative research. *International journal of qualitative methods*, 1(2), 13-22.
- Mulisa, F. (2022) When Does a Researcher Choose a Quantitative, Qualitative, or Mixed Research Approach? *Interchange*, 53(1), 113-131.
- Mwita, K. (2022) Factors influencing data saturation in qualitative studies. Available at SSRN 4889752.
- Myers, D. (2022) *Construction economics: A new approach*. Routledge.
- Nadeem, A., Wong, A.K. and Wong, F.K. (2015) Bill of quantities with 3D views using building information modeling. *Arabian Journal for Science and Engineering*, 40, 2465-2477.

- Naoum, S.G. (2016) Factors influencing labor productivity on construction sites: A state-of-the-art literature review and a survey. *International Journal of Productivity and Performance Management*, 65(3), 401-421.
- Nassereddine, H., Hanna, A.S., Veeramani, D. and Lotfallah, W. (2022) Augmented reality in the construction industry: use-cases, benefits, obstacles, and future trends. *Frontiers in Built Environment*, 8, 730094.
- Navaratnam, S., Satheeskumar, A., Zhang, G., Nguyen, K., Venkatesan, S. and Poologanathan, K. (2022) The challenges confronting the growth of sustainable prefabricated building construction in Australia: Construction industry views. *Journal of Building Engineering*, 48, 103935.
- Nawi, M., Baluch, N. and Bahauddin, A.Y. (2014) Impact of fragmentation issue in construction industry: An overview.
- Nayak, M. and Narayan, K. (2019) Strengths and weaknesses of online surveys. *technology*, 6(7), 0837-2405053138.
- Nazarov, V.L., Zherdev, D.V. and Averbukh, N.V. (2021) Shock digitalisation of education: The perception of participants of the educational process.
- Neuman, W.L. (1997) *Social research methods: Qualitative and quantitative approaches*. London: Allyn & Bacon.
- Neumann, P.J., Stone, P.W., Chapman, R.H., Sandberg, E.A. and Bell, C.M. (2000) The quality of reporting in published cost-utility analyses, 1976–1997. *Annals of Internal Medicine*, 132(12), 964-972.
- Neve, H.H., Wandahl, S., Lindhard, S., Teizer, J. and Lerche, J. (2020) Determining the relationship between direct work and construction labor productivity in North America: Four decades of insights. *Journal of Construction Engineering and Management*, 146(9), 04020110.
- Ngubane, M.Z., Mndebele, S. and Kaseeram, I. (2023) Economic growth, unemployment and poverty: Linear and non-linear evidence from South Africa. *Heliyon*, 9(10).
- Nguyen, T.A., Nguyen, P.T. and Do, S.T. (2020) Application of BIM and 3D laser scanning for quantity management in construction projects. *Advances in Civil Engineering*, 2020(1), 8839923.
- Niazi, G.A. and Painting, N. (2017) Significant Factors Causing Cost Overruns in the Construction Industry in Afghanistan. *7th International Conference on Engineering, Project and Production Management*, 182, 510-517.
- Nikmehr, B., Hosseini, M.R., Martek, I., Zavadskas, E.K. and Antucheviciene, J. (2021) Digitalization as a strategic means of achieving sustainable efficiencies in construction management: A critical review. *Sustainability*, 13(9), 5040.
- Noor, S., Tajik, O. and Golzar, J. (2022) Simple random sampling. *International Journal of Education & Language Studies*, 1(2), 78-82.
- Oesterreich, T.D. and Teuteberg, F. (2016) Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in industry*, 83, 121-139.
- Ofori, G., Hindle, R. and Hugo, F. (1996a) Improving the construction industry of South Africa: A strategy. *Habitat International*, 20(2), 203-220.
- Ofori, G., Hindle, R. and Hugo, F. (1996b) Improving the Construction Industry of South Africa. *Habitat International*, 20(2), 203-220.
- Ojala, A., Evers, N. and Sousa, C.M. (2022) Digitalisation, digital services and companies' internationalisation: A literature review. *Sustainable international business models in a digitally transforming world*, 3-17.

- Okorafor, C., Emuze, F. and Das, D.K. (2016) Managing Construction Labour Productivity Improvement in Gauteng. International Conference on infrastructure Development in Africa.
- Olatunji, S.O., Olawumi, T.O. and Aje, I.O. (2017) Rethinking partnering among quantity-surveying firms in Nigeria. *Journal of Construction Engineering and Management*, 143(11), 05017018.
- Olawale, Y.A. and Sun, M. (2010) Cost and time control of construction projects: Inhibiting factors and mitigating measures in practice. *Construction Management and Economics*., 28(5), 509–526.
- Oliss, B., McFaul, C. and Riddick, J.C. (2023) The global distribution of STEM graduates: Which countries lead the way? Center for Security and Emerging Technology. Last modified November, 27.
- Olomolaiye, P., Wahab, K. and Price, A. (1987) Problems influencing craftsman productivity in Nigeria. *Building and Environment*, 22(4), 317-323.
- Omari, R.A., Sweis, G., Abu-Khader, W. and Sweis, R. (2023) Barriers to the adoption of digitalization in the construction industry: Perspectives of owners, consultants, and contractors. *Construction Economics and Building*, 23(3/4), 87-106.
- Omotayo, T., Egbelakin, T., Ogunmakinde, O. and Sojobi, A. (2024) *Innovations, disruptions and future trends in the global construction industry*. Routledge London, UK.
- Osman, Y.A.T.E.M. and Ahmed, Y.H. (2017) Estimate of labour productivity in sudanese construction industry. *Sudan Engineering Society Journal*, 63(1), 23-30.
- Osunsanmi, T.O., Aigbavboa, C. and Oke, A. (2018) Construction 4.0: the future of the construction industry in South Africa. *International Journal of Civil and Environmental Engineering*, 12(3), 206-212.
- Pallant, J. (2020) *SPSS survival manual: A step by step guide to data analysis using IBM SPSS*. Routledge.
- Papadonikolaki, E., Krystallis, I. and Morgan, B. (2020) Digital transformation in construction- Systematic literature review of evolving concepts.
- Papulová, Z., Gažová, A. and Šufliarský, L. (2022) Implementation of automation technologies of industry 4.0 in automotive manufacturing companies. *Procedia Computer Science*, 200, 1488-1497.
- Park, H.-S. (2006) Conceptual Framework of Construction Productivity Estimate. *Journal of Civil Engineering*, 10(5), 311-317.
- Parusheva, S. and Aleksandrova, Y. (2022) Legislation and policies for digitalization supporting construction innovation. *Eng. Sci*, 59(1), 71-79.
- Paulmakesh, A. and Makebo, G.M. (2022) A case study of price fluctuation in the construction industry. In, *AIP Conference Proceedings*. AIP Publishing, Vol. 2426.
- Petrov, I. and Hakimov, A. (2019) March. Digital technologies in construction monitoring and construction control. In *IOP conference series: Materials Science and Engineering*., 497((No. 1, p. 012016). IOP Publishing.).
- Philbeck, T. and Davis, N. (2018) The fourth industrial revolution. *Journal of International Affairs*, 72(1), 17-22.
- Purwanto, A. and Sudargini, Y. (2021) Partial least squares structural equation modeling (PLS-SEM) analysis for social and management research: a literature review. *Journal of Industrial Engineering & Management Research*, 2(4), 114-123.
- Rahman, M. (2016) The Advantages and Disadvantages of Using Qualitative and Quantitative Approaches and Methods in Language “Testing and Assessment” Research: A Literature Review’. *Journal of Education*

and Learning., 6(1).

- Rakgoale, T.I., Bag, S. and Pretorius, J.H.C. (2024) Analysis of barriers to the successful implementation of digitalization in South Africa using the interpretive structural modelling approach. *Global Business Review*, 09721509241246253.
- Rasinger, S.M. (2013) Quantitative research in linguistics: An introduction. A & C Black.
- Rathnayake, A. and Middleton, C. (2023) Systematic review of the literature on construction productivity. *Journal of Construction Engineering and Management*, 149(6), 03123005.
- Regona, M., Yigitcanlar, T., Hon, C. and Teo, M. (2024) Artificial intelligence and sustainable development goals: Systematic literature review of the construction industry. *Sustainable Cities and Society*, 105499.
- Rhodes, S.D., Bowie, D.A. and Hergenrather, K.C. (2003) Collecting behavioural data using the world wide web: considerations for researchers. *Journal of Epidemiology & Community Health*, 57, 68-73.
- Riazi, A.M. (2016) *The Routledge encyclopedia of research methods in applied linguistics*. Routledge.
- Riazi, S.R.M., Zainuddin, M.F., Nawi, M.N.M., Musa, S. and Lee, A. (2020) A critical review of fragmentation issues in the construction industry. *Journal of Talent Development and Excellence*, 12(2), 1510-1521.
- Ribeirinho, M.J., Mischke, J., Strube, G., Sjödin, E., Blanco, J.L., Palter, R., Biörck, J., Rockhill, D. and Andersson, T. (2020) The next normal in construction: How disruption is reshaping the world's largest ecosystem. McKinsey & Company.
- Riger, S. and Sigurvinsdottir, R. (2016) Thematic analysis. *Handbook of methodological approaches to community-based research: Qualitative, quantitative, and mixed methods*, 33-41.
- Rihoux, B. and Ragin, C.C. (2008) *Configurational comparative methods: Qualitative comparative analysis (QCA) and related techniques*. Sage Publications.
- Rocco, T.S. and Plakhotnik, M.S. (2009) Literature reviews, conceptual frameworks, and theoretical frameworks: Terms, functions, and distinctions. *Human resource development review*, 8(1), 120-130.
- Russell, B. (1914) Definitions and methodological principles in theory of knowledge. *The Monist*, 582-593.
- Sacks, R. and Barak, R. (2010) Teaching building information modeling as an integral part of freshman year civil engineering education. *Journal of professional issues in engineering education and practice*, 136(1), 30-38.
- Sanni-Anibire, M.O., Mohamad Zin, R. and Olatunji, S.O. (2022) Causes of delay in the global construction industry: a meta analytical review. *International Journal of Construction Management*, 22(8), 1395-1407.
- Saunders, M. (2009) *Research methods for business students*. Person Education Limited.
- Saunders, M., Lewis, P. and Thornhill, A. (2003) *Research methods For Business Students*. Essex: Prentice Hall: Financial Times.
- Saunders, M., Lewis, P. and Thornhill, A. (2015) *Research methods. Business Students* 4th edition Pearson Education Limited, England.
- Schober, K.S., Hoff, P. and Nölling, K. (2016) Digitalisation in the Construction Industry. Building Europe's road to "Construction 4.0". Roland Burger.
- Seadon, J. and Tookey, J.E. (2019) Drivers for construction productivity. *Engineering, Construction and Architectural Management*, 26(6), 945-961.
- Shiha, A. and Dorra, E.M. (2023) Resilience index framework for the construction industry in developing countries. *Journal of Construction Engineering and Management*, 149(4), 04023008.

- Shikalepo, E.E. (2020) Defining a conceptual framework in educational research. Namibia University of Science and Technology 7p.
- Shojaei, R.S. and Burgess, G. (2022) Non-technical inhibitors: Exploring the adoption of digital innovation in the UK construction industry. *Technological Forecasting and Social Change*, 185, 122036.
- Siddiqui, F.H., Thaheem, M.J. and Abdekhodae, A. (2023) A review of the digital skills needed in the construction industry: towards a taxonomy of skills. *Buildings*, 13(11), 2711.
- Siddiqui, F.H.,
Abdekhodae, A.
- Thaheem, M.J., (2022) Taxonomy of Digital Skills Needed in the Construction Industry: A Literature Review.
- Simushi, S. and Wium, J. (2020) Time and cost overruns on large projects: understanding the root cause. *Journal of Construction in Developing Countries*, 25(1).
- Singh, H. and Singh, A. (2002) Principles of complexity and chaos theory in project execution: A new approach to management. *Cost Engineering*, 44(12), 23-33.
- Skinner, B.F. (1956) A case history in scientific method. *American Psychologist*, 11(5), 221-233.
- Smallwood, J.J., Allen, C.J. and Deacon, C.H. (2020) The role of industry 4.0 in construction occupational health (OH). *Management*, 495, 504.
- Smidt, H.J. and Jokonya, O. (2022) Factors affecting digital technology adoption by small-scale farmers in agriculture value chains (AVCs) in South Africa. *Information Technology for Development*, 28(3), 558-584.
- Smith, J. and Noble, H. (2014) Bias in research. *Evidence-based nursing*, 17(4), 100-101.
- Soekiman, A., Priyadi, K.S., Soemardi, B.W. and Wirahadikusumah, R.D. (2011) Factors Relating to Labour Productivity Affecting the Project Schedule Performance in Indonesia. *Procedia Engineering*, 14, 865-873.
- StatsSA (2021) Quarterly Labour Force Survey (QLFS) – Q3:2021. Statistics South Africa.
- StatsSA (2022) Quarterly Labour Force Survey (QLFS) – Q2:2022.
- StatsSA (2025) Quarterly Labour Force Survey Quarter 1: 2025. Statistics South Africa
- Stearns, P.N. (2020) The industrial revolution in world history. Routledge.
- Strange, R. and Zucchella, A. (2017) Industry 4.0, global value chains and international business. *Multinational Business Review*, 25(3), 174-184.
- Subedi, D. (2016) Explanatory sequential mixed method design as the third research community of knowledge claim. *American Journal of Educational Research*, 4(7), 570-577.
- Sui Pheng, L., Shing Hou, L., Pheng, L.S. and Hou, L.S. (2019) The economy and the construction industry. *Construction Quality and the Economy: A Study at the Firm Level*, 21-54.
- Sürücü, L. and Maslakci, A. (2020) Validity and reliability in quantitative research. *Business & Management Studies: An International Journal*, 8(3), 2694-2726.
- Sutherland, E. (2020) The fourth industrial revolution—the case of South Africa. *Politikon*, 47(2), 233-252.
- Sveikauskas, L., Rowe, S., Mildenerger, J., Price, J. and Young, A. (2016) Productivity Growth in Construction. *Journal of Construction Engineering and Management*, 142(10).
- Sweis, G.J. (2000) Impact of conversion technology on productivity in masonry construction. Dissertation, Field of Civil Engineering, Northwestern University, Evanston, IL.

- Taalbi, J. (2019) Origins and pathways of innovation in the third industrial revolution. *Industrial and corporate change*, 28(5), 1125-1148.
- Taber, K.S. (2018) The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in science education*, 48(6), 1273-1296.
- Taherdoost, H. (2016a) Sampling methods in research methodology; how to choose a sampling technique for research. *International journal of academic research in management (IJARM)*, 5.
- Taherdoost, H. (2016b) Validity and reliability of the research instrument; how to test the validation of a questionnaire/survey in a research. *International journal of academic research in management (IJARM)*, 5.
- Tashakkori, A. and Teddlie, C. (2003) Issues and dilemmas in teaching research methods courses in social and behavioural sciences: US perspective. *International journal of social research methodology*, 6(1), 61-77.
- Teddlie, C. and Yu, F. (2007a) Mixed methods sampling: A typology with examples. *Journal of mixed methods research*, 1(1), 77-100.
- Teddlie, C. and Yu, F. (2007b) Mixed methods sampling: A typology with examples. *Journal of mixed methods research*, 1(1), 77-100.
- Thacker, L.R. (2020) What is the big deal about populations in research? In: SAGE Publications Sage CA: Los Angeles, CA, 3-3.
- Thomas, A. (2012) Constructing conceptual frameworks: Building the route. Sharon, FR & Gretchen, BR *The research journey: Introduction to inquiry*, 89.
- Tjebane, M.M., Musonda, I. and Okoro, C. (2022) Organisational factors of artificial intelligence adoption in the South African construction industry. *Frontiers in Built Environment*, 8, 823998.
- Tran, H.V.V. and Nguyen, T.A. (2024) A review of challenges and opportunities in BIM adoption for construction project management. *Engineering Journal*, 28(8), 79-98.
- Trask, C. and Linderoth, H.C. (2023) Digital technologies in construction: A systematic mapping review of evidence for improved occupational health and safety. *Journal of Building Engineering*, 80, 108082.
- UN (2015). Available: <https://www.un.org/sustainabledevelopment/infrastructure-industrialization/> [Accessed 10 November 2024, 2025].
- Usakli, A. and Rasoolimanesh, S.M. (2023) Which SEM to use and what to report? A comparison of CB-SEM and PLS-SEM, *Cutting edge research methods in hospitality and tourism*, pp. 5-28: Emerald Publishing Limited.
- van Wyk, L., Kajimo-Shakantu, K. and Opawole, A. (2024a) Adoption of innovative technologies in the South African construction industry. *International Journal of Building Pathology and Adaptation*, 42(3), 410-429.
- van Wyk, L., Kajimo-Shakantu, K. and Opawole, A. (2024b) Adoption of innovative technologies in the South African construction industry. *International Journal of Building Pathology and Adaptation*, 42(3), 410-429.
- Varpio, L., Paradis, E., Uijtdehaage, S. and Young, M. (2020) The distinctions between theory, theoretical framework, and conceptual framework. *Academic medicine*, 95(7), 989-994.
- Verhoogen, E. (2023) Firm-level upgrading in developing countries. *Journal of Economic Literature*, 61(4), 1410-1464.
- Victora, C.G., Huttly, S.R., Fuchs, S.C. and Olinto, M.T. (1997) The role of conceptual frameworks in epidemiological analysis: a hierarchical approach. *International journal of epidemiology*, 26(1), 224-227.

- Von Broembsen, M., Wood, E. and Herrington, M. (2005) Global entrepreneurship monitor: South African report 2005. The UCT Centre for Innovation and Entrepreneurship, 14-27.
- Wang, M., Wang, C.C., Sepasgozar, S. and Zlatanova, S. (2020) A systematic review of digital technology adoption in off-site construction: Current status and future direction towards industry 4.0. *Buildings*, 10(11), 204.
- Wang, X., Wang, X. and Huang, Y. (2019) Chinese construction worker reluctance toward vocational skill training. *Journal of Engineering, Design and Technology*, 17(1), 155-171.
- Warrens, M.J. (2014) On Cronbach's Alpha as the Mean of All Possible-Split Alphas. *Advances in Statistics*.
- Werner, T. and Lehan, A. (2023) Enterprise Architecture Management (EAM) as a fundamental approach for the digital transformation of the German road infrastructure management. *Transportation Research Procedia*, 72, 1098-1104.
- William, F.K.A. (2024) My data are ready, how do I analyze them: navigating data analysis in social science research. *International Journal of Scientific Research and Management*, 12(3), 1730-1741.
- Wyman, O. (2018) DIGITALIZATION OF THE CONSTRUCTION INDUSTRY: THE REVOLUTION IS UNDERWAY.
- Yi, W. and Chan, A.P.C. (2014) Critical Review of Labour Productivity Research in Construction Journals. *Journal of Management in Engineering*, 30(2), 214-225.
- Zhang, K., Gonzalez, R., Huang, B. and Ji, G. (2014) Expectation-maximization approach to fault diagnosis with missing data. *IEEE Transactions on Industrial Electronics*, 62(2), 1231-1240.
- Zhang, Z., Fang, H., Li, B. and Wang, F. (2020) Mechanical properties of concrete pipes with pre-existing cracks. *Applied Sciences*, 10(4), 1545.
- Zhong, Q., Tang, H. and Chen, C. (2022) A framework for selecting construction project delivery method using design structure matrix. *Buildings*, 12(4), 443.
- Zhou, F., Ning, Y., Guo, X. and Guo, S. (2023) Analyze differences in carbon emissions from traditional and prefabricated buildings combining the life cycle. *Buildings*, 13(4), 874.
- Zhou, Z., Irizarry, J. and Li, Q. (2014) Using network theory to explore the complexity of subway construction accident network (SCAN) for promoting safety management. *Safety Science*, 64(127-136).
- Žukauskas, P., Vveinhardt, J. and Andriukaitienė, R. (2018) Philosophy and paradigm of scientific research. *Management culture and corporate social responsibility.*, 121, 139.

APPENDIX A – ETHICS APPROVAL



2024/06/27
EBE/00686/2024

RE: Research Ethics Committee Project Approval Letter

Dear Mochelo Lefoka, (Principal Investigator)

Your application for ethics review of your project titled

MODELLING THE ADOPTION OF DIGITAL TECHNOLOGIES AND PRODUCTIVITY IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

has been reviewed and evaluated by the

Faculty of Engineering & Built Environment Research Ethics Committee (REC).

Based on the information supplied your application has been successful and is approved.

You may proceed with your research project.

Please note that should:

- (i) any serious or adverse effects to participants occur and/or,
- (ii) aspect(s) of your current project change and/or
- (iii) any unforeseen events that might affect continued ethical acceptability of the project occur then you should immediately report this to the approving REC. You may be required to submit an amendment to this application, in order to determine whether the changed aspects increase the ethical risks of your project.

Please note the following additional conditions associated with this approval:

- (i) You are still declaring both options regarding conflicts of interest, but these are mutually exclusive. Please, by email to the Chair of the EBE REC, cc. to your supervisor, declare whether you do or do not have a real, potential or perceived conflict of interest.

Regards,

Harro Von Blottnitz
Chairperson
Engineering & Built Environment Committee

APPENDIX B1 – CONCENT FORM



Engineering and the built Environment Faculty (EBE)
Construction, Economics and Management Department (CEM).
University of Cape Town (UCT), Cape Town, South Africa.
Rondebosch, 7701.

MODELLING THE ADOPTION OF DIGITALISATION TECHNOLOGIES AND PRODUCTIVITY IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

Good day participant, my name is Mr Mochelo Lefoka, a PhD candidate at the University of Cape Town (UCT). I am currently conducting a study titled: Modelling the Adoption of Digitalisation Technologies and Productivity in the South African Construction Industry. The focal objective of this research is to examine the readiness, the ability, the adoption as well as the proficiency of the various digital technologies adopted on a construction project. This is to understand the kind of impact (negative/positive) on the levels of productivity observed over the project life cycle from the design to the completion stage of the project. Furthermore, understand how contextual factors create variances between the estimated labour productivity and the actual on construction projects. Your invitation to this study is largely based on the role you play in the management and supervision of construction projects that demand the integration of digital technologies with traditional methods of building to enhance or improve the levels of productivity (or the adverse).

The questionnaire would take you approximately 25 minutes to complete as the questionnaire is largely based on experiential and information from the most recent project you have managed within the last five years. The questionnaire has two sections. The first section largely collects background information such as your personal qualification and experience in the construction industry. While the second section of the questionnaire collects more technical and project specific information.

Please note that the research is not in any way linked or connected to the construction organisation you are affiliated with. As a result, the company will not have any access to your answers to the questions you provide in this questionnaire. All the information provided is anonymised, treated with confidentiality, and not connected or linked to you in any way or form. The data collected from this research will be analysed and presented in an aggregated format and as a result, the singular or specific identification of participants will be circumvented.

Kindly complete all the sections of this questionnaire as all the questions posed are important for this study to reach its objective. Additionally, it is imperative to note that you are free to withdraw your participation in this study at any given point when completing this questionnaire/or your participation. There will be no penalty, negative consequences, or any ill will towards your decision to withdraw your participation.

Please do not hesitate to contact the researcher in case you have any questions, require additional information or have any queries regarding this study, on:

Researcher: Mochelo Lefoka, University of Cape Town (UCT)

Contact: +27 (0) 21 650 1416

Email Address: lfkmoc001@myuct.ac.za

Research Supervisor: Professor Abimbola Windapo

Email Address: abimbola.windapo@myuct.ac.za

Thank you for your participation in this research. Your participation in this study is deeply appreciated.

APPENDIX B2 – RESEARCH QUESTIONNAIRE

SECTION 1: PERSONAL INFORMATION/PARTICIPANT PERSONAL QUESTIONS.

1 Please indicate your age range:

< 25 years	
25 – 34 years	
34 – 44 years	
45 – 54 years	
55 – 64 years	
>65 years	

2 Please indicate your highest academic qualification.

BSc/BEng degree/Diploma	
Honours/BTech degree	
MSc/MBA	
PhD	
Other (please specify)	

3 Please indicate how many years of experience you have in the construction industry? (E.g 5 years)

< 5 years	
6 – 10 years	
11 – 15 years	
16 – 20 years	
21 – 30 years	
>30 years	

4 What is your current designation/job description?

Director Cadre	
Contracts Manager	
Project Manager	
Site Agent	
Construction Manager	
Site Engineer	
Construction supervisor	
Quantity Surveyor	
Estimator	
Cost Engineer	
Other (please specify)	

5 Please list all the professional councils in South Africa, you are registered or affiliated with (please tick all that is applicable).

ECSA	
SACPCMP	
CIDB	
SACAP	
CIOB	
PMAQS	
MRICS	
Other (please specify)	

6 Kindly indicate what profession you identify with in your current role in your organisation?

Construction Manager (CM)	
Contracts Director	
Contracts Manager	
Project Manager (PM)	
Quantity Surveyor (QS)	
Civil Engineer/Structural Engineer	
Architect	
Mechanical Engineer	
Other (please specify)	

7 Please indicate the province in which you are currently working in South Africa.

Province	
Mpumalanga	
Limpopo	
Gauteng	
North-West	
Free State	
Kwa-Zulu Natal	
Northern Cape	
Eastern Cape	
Western Cape	

8 Please indicate the grade of your organisation/company on the Construction Industry Development Board (cidb) Register of Contractors (if applicable). Please tick all the categories that apply to your relevant grade.

Category	cidb Grade								
	1	2	3	4	5	6	7	8	9
General Building									
Civil Engineering									
Electrical Engineering Works - Building									
Electrical Engineering Works - Infrastructure									
Mechanical Works									
Asphalt									
Lateral Earth Support									
Anodic and electrolytic									
Demolition & Blasting									
Sprinkler System and Fire installation									
Curtain walls and shop fronts									
Landscaping and horticultural specialists									
Lifts, escalators and hoisting machinery									
Specialised foundations									
Road markings and signage									
Structural steelwork and scaffolding									
Timber buildings structure									
Waterproofing specialists									
Wet services and plumbing									
Fencing and Hoarding specialists									
Other (Please specify)									
.....									

9 Can you give an example of how the implementation of digital technology significantly impacted the outcome or productivity of the construction project identified? Please refer to a specific project you

have worked on in the past 3 years. “Never” (10 – 20%), “rarely” (20 - 40%), “sometimes” (40 – 60%), “Often (meaning that it is used often and “Always” (70 - 100%) meaning that it is always used”.

	Never	Rarely	Sometimes	Often	Always
Minimises design costs					
Improves construction productivity on-site					
Information transparency amongst the professional team					
Risk reduction due to shared digital resources					
Decreases the construction period					
Improves the quality of the development (building)					
Allows for quick information transfer					
Efficient communication					
Improved project productivity					
Enhancing safety - quick detection					
Other (Please specify)					
.....					

10 Please identify a project you have worked on and completed in the past three years and indicate the type of project:

Project Type	
High End Housing project	
Infrastructure (building)	
Road developments	
General construction and built	
Refurbishment project	
Airport	
Railway Development	
Other (Please specify)	
.....	

11 In relation to the type of project you identified in Question 10 and completed in the past three years, please indicate the initial planned completion time of the project (in years).

.....

12 Please indicate the final (actual) completion time of the project in question (in years)

.....

13 Please indicate the initial budgeted amount for the project identified in Question 10 (in Rand

.....

14 Please indicate the final (actual) cost of completion for the project you identified in Question 10 (in Rands)

.....

SECTION 2: TECHNICAL INFORMATION: TYPES OF DIGITAL TOOLS AND TECHNOLOGIES.

15 Please go through the list in the following table and identify the digital technologies (software) you used on. Please refer to a specific project you have worked on in the past 3 years. “Never” (10 – 20%), “rarely” (20 - 40%), “sometimes” (40 – 60%), “Often (meaning that it is used often) and “Always” (70 - 100%) meaning that it is always used”.

Type of digital tool or technique used	Probability of use				
	Never	Rarely	Sometimes	Often	Always
Augmented Reality					
Building Information Software (BIM)					
Information and Communication Technology (ICT)					
Web Based Project Management (WBPM)					
Big Data and Analytics					
Internet of Things (IoT)					
Digital Twins					
Production Robots (Robotics)					
3D Printing Machines					
Drones / Scanning Drones					
Virtual Reality					
Modular Construction					
Mobile Devices (smart and handheld devices)					
Blue Beam Software					
Cloud Computing					
Virtual Prototyping					
Wearable Device (such as motion sensors and digital transmitters)					
Wireless Sensor Network (WSN)					
Other (Please specify)					

SECTION 2.1: THE DETERMINATION OF THE LEVEL OF SKILL, KNOWLEDGE AND EXPERIENCE OF THE USEFULNESS OF DIGITAL TECHNOLOGIES THROUGHOUT VARIOUS STAGES OF THE CONSTRUCTION PROJECT LIFE-CYCLE.

16 The following questions relate to your perception of the ability and required level of skill, knowledge and experience of the professional team member’s use and acquaintance with the usefulness of digital technologies outlined in Question 15 during the **planning** stage of the construction project. Where 1 represent “Not useful”, 2 represent “Slightly useful”, 3 represent “mildly useful”, 4 represent “Very useful” and 5 represent “Extremely significant”.

	1	2	3	4	5
Client					

Construction Manager (CM)					
Project Manager (PM)					
Quantity Surveyor (QS)					
Civil Engineer/Structural Engineer					
Architect					
Mechanical Engineer					
Costing Engineer/Manager					
Principal Agent					
Other (please specify)					

17 The following questions relate the ability of the required level of skill, knowledge and experience of the professional team member's use and acquaintance usefulness of digital technologies outlined in Question 15 during the **Design** stage of the construction project. Where 1 represent "Not useful", 2 represent "Slightly useful", 3 represent "mildly useful", 4 represent "Very useful" and 5 represent "Extremely useful".

	1	2	3	4	5
Client					
Construction Manager (CM)					
Project Manager (PM)					
Quantity Surveyor (QS)					
Civil Engineer/Structural Engineer					
Architect					
Mechanical Engineer					
Costing Engineer/Manager					
Principal Agent					
Other (Please specify)					

18 The following questions relate the ability of the required level of skill, knowledge and experience of the professional team member's use and acquaintance usefulness of digital technologies outlined in Question 15 during the **Building/Construction Phase** stage of the construction project. Where 1 represent "Not useful", 2 represent "Slightly useful", 3 represent "mildly useful", 4 represent "Very useful" and 5 represent "Extremely useful".

	1	2	3	4	5
Client					

Construction Manager (CM)					
Project Manager (PM)					
Quantity Surveyor (QS)					
Civil Engineer/Structural Engineer					
Architect					
Mechanical Engineer					
Costing Engineer/Manager					
Principal Agent					
Other (Please Specify)					
.....					

SECTION 2.2: THE DETERMINATION OF THE LEVEL OF THE MATRIX USED AGAINST MEASURING LEVELS OF PRODUCTIVITY ON CONSTRUCTION PROJECTS

19 The following questions relate to how project success was measured on the identified project from the planning stage through to the completion stage of the project.

Please rate the use of the following indicators of productivity used on the recently completed construction project that you identified.

	Never	Rarely	Sometimes	Often	Always
Completing the project within cost					
Completing the project within time					
Meeting the client's requirements/satisfaction					
Total Factor Productivity (TFP)					
Average Factor Productivity (AFP)					
Adherence to health and safety – No fatalities.					
Quality – Intended utility of the project					
Development of new Technological capability					
Decreased Dependence on external resources – optimisation of resources					
Increased organisational reputation					
Labourer's satisfaction during the development.					
Ability to mitigate external and internal forces on the project					

20 On a scale of 1 to 5, where 1 represents “Not significant”, 2 represents “Slightly significant”, 3 represents “somewhat significant”, 4 represents “Significant” and 5 represent “Very significant” rate

the likely factors - Environmental, organisational/Construction Firm or Technical factors that give rise to delays and cost overruns on the project identified.

Environmental Factors	1	2	3	4	5
Inclement weather (rain/cold/heat)					
Unexpected site ground conditions					
Site location/environment					
Lack of experience amongst workers					
Delays in delivery of material					
Uncertain Ground conditions (soil type) /Uncertainty in terrain					
Poor site supervision					
Lack of tools and equipment					
Mismanagement of resources on site					
Rework due to poor quality					
Other please specify					

Organisational/Construction Firm	1	2	3	4	5
Non-payment of labour					
Delays in payment of labour					
Fluctuations in material/equipment prices					
Changes in management structure					
Shortage of labour/manpower					
Inexperienced supervisors					
Lack of training on new skills					
Change in government legislature/policy					
Economic changes (change in VAT, inflation and foreign exchange rates)					
Other please specify					

Technical factors	1	2	3	4	5
Poorly designed project					
Lack of Digital Software					
Absence of digital collaboration amongst professionals					
Incomplete drawings					
Methods of construction (prefabrication vs onsite)					

Poor co-ordination/planning of activities					
Complexity of the project					
Lack of Automation (robotics)					
Buildability of the structure					
Inspection delays from engineers					
Change orders from the designers/consultants					
Other please specify					

SECTION 3: BARRIERS TO THE EFFECTIVE IMPLEMENTATION AND ADOPTION OF DIGITALISATION TECHNOLOGY.

21 Please go through the following list of reasons considered to be barriers to the implementation/adoption of digitalisation technologies in the construction industry and identify which is least significant to significant. Where 1 represent “Not significant”, 2 “Slightly significant”, 3 “somewhat significant”, 4 “Significant” and 5 “Very significant”.

Barrier	1	2	3	4	5
The lack of skills across professionals					
No training and knowledge of digital technologies					
Fragmentation of the construction process.					
Resources to pay for digital technologies (software for a digital environment)					
Aversion of stakeholders					
Uncertainty of utility of digital technologies					
Lack of investment in the use of digital technologies by both government and private sector					
Complexity of the construction project					
Lack of Technical abilities to operate digital technologies (software)					
The expense and cumulative operation costs to the organisation.					
Other please specify					

SECTION 4.1: ENABLERS OF THE EFFECTIVE IMPLEMENTATION AND ADOPTION OF DIGITALISATION TECHNOLOGY ON CONSTRUCTION PRODUCTIVITY.

22 Please go through the following list of reasons that are considered to be enablers of the implementation of digitalisation technologies in the construction industry and rate them on a scale of 1 to 5, where 1 represents “Not significant”, 2 represents “Slightly significant”, 3 represents “somewhat significant”, 4 represents “significant” and 5 represents “Very significant”.

Enabler	1	2	3	4	5
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Amend the JBCC/FIDIC to enforce digitalisation to be an integral of public and private contracts tendering process.					
Construction professionals to operate with legislature fostering use of digital tools (through design to construction phase)					
Collaborative relations across professionals					
Adopt construction waste management (Lean construction)					
Investment by companies into new digital technologies and software					
Upskilling/training of construction personnel					
Construction specialised entrepreneurship					
Inability of the construction industry to adapt to new technologies and new methods of construction – risk averse.					
Automation (utilisation of robotics).					
Other (Please specify)					

SECTION 4.2: TRAINING OF THE WORKFORCE AND THE LABOUR COMPONENT (AS WELL AS THE PROFESSIONAL TEAM IN RELATION TO DIGITAL TECHNOLOGIES/SOFTWARES)

23 In your organisation, what kind of training do you offer the workforce and the professional team in Acquainting them with new digital technologies (and software). Please refer to one of the projects you have worked on in the past 3 years where “Never” (10 – 20%), “rarely” (20 - 40%), “sometimes” (40 – 60%), “Often (meaning that it is used often and “Always” (70 - 100%) meaning that it is always used”.

Type of digital tool or technique used	Probability of use				
	Never	Rarely	Sometimes	Often	Always
Augmented Reality					
Building Information Software (BIM					
Information and Communication Technology (ICT)					
Web Based Project Management (WBPM)					
Big Data and Analytics					
Internet of Things (IoT					
Digital Twins					
Production Robots (Robotics)					
3D Printing Machines					
Drones / Scanning Drones					
Virtual Reality					
Modular Construction					
Mobile Devices (smart and handheld devices)					
Blue Beam Software					

Cloud Computing					
Virtual Prototyping					
Wearable Device (such as motion sensors and digital transmitters)					
Wireless Sensor Network (WSN)					

SECTION 4.3: BENEFITS OF TRAINING AND EQUIPING THE WORKFORCE AND THE PROFESSIONAL TEAM WITH NECESSARY TRAINING AND UP-SKILLING.

24 In your organisation, how often do you train and upskill the new workers (and existing workers and the professional team) on the proficiency, utilisation and adopting of the new digital tools and software introduced to increase productivity on construction projects. Where “Never” (10 – 20%), “rarely” (20 - 40%), “sometimes” (40 – 60%), “Often (meaning that it is used often and “Always” (70 - 100%) meaning that it is always used”.

	Never	Rarely	Sometimes	Often	Always
Daily					
Weekly					
Bi-weekly					
Monthly					
Fortnightly					
As soon as an employee is in a position to be part of the management team.					
Upon the procurement of a digital tool (software in the company)					
On request					
Other (please specify)					

25 Please refer to a specific project you have worked on in the past three years, have you found these digital technology tools (software trainings) sessions to be effective in enhancing and improving the levels of labour productivity and project success? rate them on a scale of 1 to 5, where 1 represents “Not significant”, 2 represents “Slightly significant”, 3 represents “somewhat significant”, 4 represents “significant” and 5 represents “Very significant”.

	1	2	3	4	5
Labour productivity has improved on site					
Document control is better streamlined					
Errors in designs have decreased					
An improvement in collaborative work has improved					
Projects gets completed on time					
Projects gets completed within budget					
Minimal wastage is observed					
Client satisfaction is always achieved					

Other (please specify					
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END OF QUESTIONNAIRE

APPENDIX C – INTERVIEW SCHEDULE

SECTION 1: INTERVIEW QUESTIONS.

1 Please indicate your highest academic qualification.....

BSc/BEng degree/Diploma	
Honours/BTech degree	
MSc/MBA	
PhD	
Other (please specify)	

2 Please indicate how many years of experience you have in the construction industry/built environment?
(E.g 5 years)

< 5 years	
6 – 10 years	
11 – 15 years	
16 – 20 years	
21 – 30 years	
>30 years	

3 What is your current designation/job description?.....

Director Cadre	
Contracts Manager	
Project Manager	
Site Agent	
Construction Manager	
Site Engineer	
Construction supervisor	
Quantity Surveyor	
Estimator	
Cost Engineer	
Other (please specify)	

4 Please list all the professional councils in South Africa, you are registered or affiliated with (please tick all that is applicable)

ECSA	
SACPCMP	
CIDB	
SACAP	
CIOB	

PMAQS	
MRICS	
Other (please specify)	

5 Please indicate the province in which you are currently working in South Africa.....

Province	
Mpumalanga	
Limpopo	
Gauteng	
North-West	
Free State	
Kwa-Zulu Natal	
Northern Cape	
Eastern Cape	
Western Cape	

6 Please indicate the grade of your organisation/company on the Construction Industry Development Board (cidb) Register of Contractors (if applicable).

.....

7 Are you able to give an example of how the implementation of digital technology significantly impacted the outcome or productivity of the construction project you previously worked on?

8 In relation to the type of project you identified in Question 7 and completed in the past three years, please indicate the initial planned completion time of the project (in years).

.....

9 Please indicate the final (actual) completion time of the project in question (in years)

.....

10 Please indicate the initial budgeted amount for the project identified in Question 10 (in Rand

.....

11 Please indicate the final (actual) cost of completion for the project you identified in Question 10 (in Rands)

.....

12 What are types of digital tool or technique used in the construction industry in your experience?.....

13 From a **Planning** stage, of a construction project, how significant do you think digitalisation is?

14 From a **Design** stage of a construction project, how significant do you think digitalisation is?

.....

15 From a **Building/Construction Phase** stage of a construction project, how significant do you think digitalisation is?

.....

16 What are some of the Environmental, Organisation or Technical factors do you think make it difficult for companies in South Africa to implement digitalisation?

.....

17 What are the fundamental **Barriers** to digitalisation in the South African construction industry in your experience?

.....

18 What are the fundamental **Enablers** to digitalisation in the South African construction industry in your experience?

.....

19 Are companies willing to train its employees in the use of digital technologies, given the cost and time component of such a training?"

END OF QUESTIONNAIRE

APPENDIX D – RESULTS OF KRUSKAL-WALLIS FOR GENERAL BUILDING (GB)

Hypothesis Test Summary				
	Null Hypothesis	Test	Sig. ^{a,b}	Decision
1	The distribution of DT1 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,223	Retain the null hypothesis.
2	The distribution of DT2 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,053	Retain the null hypothesis.
3	The distribution of DT3 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,414	Retain the null hypothesis.
4	The distribution of DT4 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,145	Retain the null hypothesis.
5	The distribution of DT5 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,102	Retain the null hypothesis.
6	The distribution of DT6 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,533	Retain the null hypothesis.
7	The distribution of DT7 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,039	Reject the null hypothesis.
8	The distribution of DT8 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,079	Retain the null hypothesis.
9	The distribution of DT9 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,589	Retain the null hypothesis.
10	The distribution of DT10 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,019	Reject the null hypothesis.
11	The distribution of DT11 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,359	Retain the null hypothesis.
12	The distribution of DT12 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,097	Retain the null hypothesis.

13	The distribution of DT13 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,852	Retain the null hypothesis.
14	The distribution of DT14 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,705	Retain the null hypothesis.
15	The distribution of DT15 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,361	Retain the null hypothesis.
16	The distribution of DT16 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,130	Retain the null hypothesis.
17	The distribution of DT17 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,030	Reject the null hypothesis.
18	The distribution of DT18 is the same across categories of General_Building_CIDB.	Independent-Samples Kruskal-Wallis Test	0,037	Reject the null hypothesis.
a. The significance level is .050.				
b. Asymptotic significance is displayed.				

APPENDIX E – RESULTS OF KRUSKAL-WALLIS FOR CIVIL ENGINEERING (CE)

Hypothesis Test Summary				
	Null Hypothesis	Test	Sig. ^{a,b}	Decision
1	The distribution of DT1 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,973	Retain the null hypothesis.
2	The distribution of DT2 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,173	Retain the null hypothesis.
3	The distribution of DT3 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,017	Reject the null hypothesis.
4	The distribution of DT4 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,199	Retain the null hypothesis.
5	The distribution of DT5 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,396	Retain the null hypothesis.
6	The distribution of DT6 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,188	Retain the null hypothesis.
7	The distribution of DT7 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,762	Retain the null hypothesis.
8	The distribution of DT8 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,740	Retain the null hypothesis.
9	The distribution of DT9 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,950	Retain the null hypothesis.
10	The distribution of DT10 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,755	Retain the null hypothesis.
11	The distribution of DT11 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,899	Retain the null hypothesis.

12	The distribution of DT12 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,549	Retain the null hypothesis.
13	The distribution of DT13 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,845	Retain the null hypothesis.
14	The distribution of DT14 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,638	Retain the null hypothesis.
15	The distribution of DT15 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,260	Retain the null hypothesis.
16	The distribution of DT16 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,910	Retain the null hypothesis.
17	The distribution of DT17 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,686	Retain the null hypothesis.
18	The distribution of DT18 is the same across categories of Civil_Engineering_CIDB.	Independent-Samples Kruskal-Wallis Test	0,697	Retain the null hypothesis.
a. The significance level is .050.				
b. Asymptotic significance is displayed.				

APPENDIX F – RESULTS OF KRUSKAL-WALLIS FOR ENVIRONMENTAL FACTORS BY LOCATION

Hypothesis Test Summary				
	Null Hypothesis	Test	Sig. ^{a,b}	Decision
1	The distribution of E1 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,803	Retain the null hypothesis.
2	The distribution of E2 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,076	Retain the null hypothesis.
3	The distribution of E3 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,292	Retain the null hypothesis.
4	The distribution of E4 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,499	Retain the null hypothesis.
5	The distribution of E5 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,160	Retain the null hypothesis.
6	The distribution of E6 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,374	Retain the null hypothesis.
7	The distribution of E7 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,247	Retain the null hypothesis.
8	The distribution of E8 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,145	Retain the null hypothesis.
9	The distribution of E9 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,312	Retain the null hypothesis.
10	The distribution of E10 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,291	Retain the null hypothesis.
a. The significance level is .050.				
b. Asymptotic significance is displayed.				

APPENDIX G – RESULTS OF KRUSKAL-WALLIS FOR ORGANISATIONAL/CONSTRUCTION FIRM FACTORS BY LOCATION

Hypothesis Test Summary				
	Null Hypothesis	Test	Sig. ^{a,b}	Decision
1	The distribution of OC1 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,365	Retain the null hypothesis.
2	The distribution of OC2 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,250	Retain the null hypothesis.
3	The distribution of OC3 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,511	Retain the null hypothesis.
4	The distribution of OC4 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,348	Retain the null hypothesis.
5	The distribution of OC5 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,736	Retain the null hypothesis.
6	The distribution of OC6 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,361	Retain the null hypothesis.
7	The distribution of OC7 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,536	Retain the null hypothesis.
8	The distribution of OC8 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,065	Retain the null hypothesis.
9	The distribution of OC9 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,004	Reject the null hypothesis.
a. The significance level is .050.				
b. Asymptotic significance is displayed.				

APPENDIX H – RESULTS OF KRUSKAL-WALLIS FOR TECHNICAL FACTORS BY LOCATION

Hypothesis Test Summary				
	Null Hypothesis	Test	Sig. ^{a,b}	Decision
1	The distribution of T1 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,143	Retain the null hypothesis.
2	The distribution of T2 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,202	Retain the null hypothesis.
3	The distribution of T3 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,423	Retain the null hypothesis.
4	The distribution of T4 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,531	Retain the null hypothesis.
5	The distribution of T5 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,860	Retain the null hypothesis.
6	The distribution of T6 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,452	Retain the null hypothesis.
7	The distribution of T7 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,035	Reject the null hypothesis.
8	The distribution of T8 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,561	Retain the null hypothesis.
9	The distribution of T9 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,929	Retain the null hypothesis.
10	The distribution of T10 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,100	Retain the null hypothesis.
11	The distribution of T11 is the same across categories of Location_Province.	Independent-Samples Kruskal-Wallis Test	0,015	Reject the null hypothesis.
a. The significance level is .050.				

b. Asymptotic significance is displayed.			
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