An assessment of the adoption of artificial intelligence (AI) in the South African construction industry

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Abstract

This research aims to assess the adoption of artificial intelligence (AI) in the South African construction industry. AI can revolutionise various sectors, including construction, by improving efficiency, productivity, and decision-making processes. However, the adoption of AI in the construction industry is still in its early stages, and its potential impact in the South African context remains largely unexplored.

The research methodology involves a comprehensive literature review to understand the current state of AI adoption in the global construction industry and identify potential barriers and challenges specific to the South African context. Additionally, primary data will be collected through surveys using questionnaires with critical stakeholders in the South African construction industry, including contractors, engineers, and project managers who are members of the Civil and Built Environment (CBE) bodies. The research aimed to identify the extent of AI adoption in the South African construction industry, assess the benefits and challenges faced by industry players, and explore the factors influencing the adoption process.

The findings provide valuable insights into the current landscape of AI adoption and inform strategies to facilitate its successful implementation in the South African construction industry. The expected outcomes of this research include a comprehensive understanding of the current state of AI adoption in the South African construction industry, identification of barriers and challenges, and recommendations for industry players and policymakers to promote the effective integration of AI technologies. The research findings will contribute to the existing knowledge on AI adoption in the construction industry and provide a basis for future research and practical applications in South Africa.

Keywords: Artificial intelligence, productivity, economics employment, construction, sustainability, safety, security, cost, policy.

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List of abbreviations

4IR: 4^{th} Industrial Revolution

ANN: Artificial Neural Networks

AEC: Architecture, Engineering and Construction

AI: Artificial Intelligence

CBE: Council for Built Environment

ECSA: Engineering Council of South Africa

ICT: Information and Communication Technology

LDCs: Less Developed Countries

ML: Machine Learning

NIST: National Institute of Standards and Technology

R&D: Research and Development

SA: South Africa

SACPCMP: South African Council of Project Management and Construction Management Professionals

SDGs: Sustainable Development Goals

SMMEs: Small Micro- Medium-sized Enterprise(s)

Chapter 1

This introductory chapter highlights the general background of the study. The chapter also outlines the study's components and provides the following structure. It includes the aim, research problem statement, questions, objectives, motivation and purpose of the study.

1. Introduction to Artifical intelligence

Adopting AI in the South African construction industry can significantly affect the industry's economics. The construction industry is a significant contributor to the South African economy, and adopting AI can lead to increased productivity, efficiency, and cost savings (Bag *et al.,* 2021). However, adopting AI in the construction industry requires significant technological and infrastructure investments (Bag *et al.,* 2021; Rauch, Dallasega, & Unterhofer, 2019). The cost of implementing AI can be a barrier to adoption, especially for Small Micro- Medium-sized Enterprise (SMME(s) (Rauch *et al.,* 2019). Therefore, adopting AI in the South African construction industry can negatively or positively impact the industry's economics.

The construction industry is a labour-intensive industry, and the adoption of AI can lead to the displacement of workers (Parschau & Hauge, 2020). Moreover, adopting AI in the construction industry can lead to job losses, especially for low-skilled workers (Parschau & Hauge, 2020). However, AI can create new job opportunities in the latest technological value chain (Parschau & Hauge, 2020). Therefore, the impact of AI adoption on the South African construction industry's economics depends on the balance between job losses and job creation.

The research question concerning organisational factors of AI adoption in the South African construction industry remains to be clarified (Rauch *et al.,* 2019). Nevertheless, AI can create more jobs in the new technological value chain (Parschau & Hauge, 2020). Therefore, it is essential to investigate the effects of AI adoption on the South African construction industry economics.

The construction industry is under-digitized, and adopting AI can increase productivity, efficiency, and cost savings (Bag *et al.,* 2021; Newman *et al*., 2021). AI can automate repetitive tasks, reduce errors, and improve safety (Tyagi *et al.,* 2021). AI can also provide real-time data analysis, which can help in decision-making and project management (Tyagi *et al.,* 2021). Therefore, the adoption of AI in the South African construction industry can have a positive impact on the industry's economy.

In conclusion, adopting AI in the South African construction industry can positively and negatively affect the industry's economy. AI can increase productivity, efficiency, and cost savings but requires significant investment in technology and infrastructure. AI can also lead to job losses, especially for low-skilled workers, but it can create new job opportunities in the latest technological value chain (Parschau & Hauge, 2020). Therefore, it is essential to carefully consider the impact of AI adoption on the South African construction industry's economics and to find a balance between the benefits and costs of AI adoption.

1.2 Study background

The construction industry in South Africa (SA) has been facing challenges in recent years, including low productivity, high costs, and a shortage of skilled labour. There has been a growing interest in adopting AI technologies to address these issues. However, there is a need to investigate the potential economic impact of AI adoption on the construction industry in SA.

AI is a wide-ranging tool that enables people to rethink how we integrate information, analyse data, and use the resulting insights to improve decision-making (West & Allen, 2018). The adoption of AI has been skyrocketing over the last 18 months, with digital innovation spurred by Covid-19 putting AI and analytics at the centre of business operations (Kuziemski & Misuraca, 2020). However, as AI spreads through society, people are worried in some ways and excited in others (Anderson *et al.,* 2018).

The impact of AI on society has been a topic of discussion for some time, with concerns raised about the ethical implications of AI adoption (Munoko *et al*., 2020). In the construction industry, AI has the potential to transform the way projects are planned, designed, and executed. For example, AECOM, an $18B per year engineering and construction services corporation, has incorporated machine learning algorithms in its in-house project management platform to achieve "100% accuracy in predicting project outcomes" (Mueller, 2016).

The adoption of AI in the construction industry in SA could have significant economic implications. AI can improve productivity, reduce costs, and increase efficiency (Golding & Nicola, 2019). For example, AI could be used to optimize the use of resources, such as labour and materials, and to improve project scheduling and management. AI could also be used to improve safety on construction sites by identifying potential hazards and risks.

However, there are also concerns about the potential impact of AI adoption on employment in the construction industry. AI has the potential to automate many tasks that are currently performed by humans, which could lead to job losses (Willcocks, 2020). There is a need to investigate the potential impact of AI adoption on employment in the construction industry in SA and to develop strategies to mitigate any adverse effects.

The adoption of AI in the construction industry in SA has the potential to transform the way projects are planned, designed, and executed. However, there is a need to investigate the potential economic impact of AI adoption, including its impact on productivity, costs, and employment. Strategies need to be developed to ensure that the benefits of AI adoption are maximised while any adverse effects are minimised.

1.2.2 Problem statement

The construction industry in South Africa is facing numerous challenges, including low productivity, high costs, and a shortage of skilled labour. The adoption of AI has the potential to address some of these challenges, but there is a lack of research on the economic effects of AI adoption in the South African construction industry. AI has the potential to revolutionize the construction industry by improving productivity, reducing costs, and enhancing safety. However, the adoption of AI in the construction industry is still in its early stages, and there is a lack of research on the economic effects of AI adoption in the South African construction industry. This assessment aims to explore the impact of AI adoption on the economics of the South African construction industry.

As cited by Pires *et al.* (2019), the report by Gartner states that the lack of skills is one of the barriers to AI adoption. This is particularly relevant in the South African context, where there is a shortage of skilled labour in the construction industry. The adoption of AI could potentially address this challenge by automating specific tasks and reducing the need for manual labour.

Nevertheless, the adoption of AI also raises ethical and societal concerns. The ethical issues surrounding AI include privacy, manipulation, bias, human-robot interaction, employment, and the effects of autonomy. These issues require careful consideration and ethical decision-making. Thus, it is crucial for organisations, policymakers, and researchers to continue discussing and addressing the ethical implications of AI to ensure its responsible and beneficial use. Moreover, as highlighted by the National Institute of Standards and Technology (NIST), AI systems can be biased, and the source of these biases can extend beyond the machine learning processes and data used to train AI software to broader societal factors (Monteith *et al.,* 2022). Therefore, it is essential to investigate the ethical and societal implications of AI adoption in the South African construction industry.

The adoption of AI has the potential to address some of the challenges facing the South African construction industry, including low productivity, high costs, and a shortage of skilled labour (Tjebane, Musonda, & Okoro, 2022). However, there is a lack of research on the economic effects of AI adoption in the South African construction industry. This assessment aims to fill this gap by exploring the impact of AI adoption on the economics of the South African construction industry. The findings of this assessment could inform the responsible and effective adoption of AI in the South African construction industry.

1.2.3 Purpose of the study

In line with the problem statement, this assessment aims to examine the effects of AI adoption on the of the South African construction industry.

1.2.4 Research questions

- What are the potential economic benefits and drawbacks of AI adoption in the South African construction industry?
- How will the AI adoption impact productivity, costs, and employment in the South African construction industry?
- What are the ethical and societal implications of AI adoption in the South African construction industry?
- How can these barriers be addressed to adopt of AI in civil engineering projects in South Africa?

1.2.5 Study objectives

- To analyse the potential economic benefits and drawbacks of AI adoption in the South African construction industry.
- To investigate the impact of AI adoption on productivity, costs, and employment in the South African construction industry.
- To explore the ethical and societal implications of AI adoption in the South African construction industry.
- To determine the barriers to the adoption of AI in civil engineering projects in South Africa.

1.2.6 Significance of the study

The promise of AI in the Fourth Industrial Revolution (4IR) is starting to materialize thanks to the availability of pertinent data, computational power, and algorithms (Cordova & Celone, 2019). To better understand how AI affects the achievement of the Sustainable Development Goals (SDG(s), this study specifically focused on goal 9—the development of infrastructure—and goal 1—the reduction of poverty—in emerging economies (United Nations, 2015). The results of the content analysis pointed to the fact that artificial intelligence has a significant impact on achieving SDG(s), particularly on reducing poverty and enhancing the security and dependability of infrastructure, such as transportation, enabling economic growth and development in emerging economies (Cordova & Celone, 2019; Vinuesa *et al.,* 2020).

1.3 Definition of terms

Artificial intelligence (AI) and machine learning (ML) - refer to the ability of machines to learn and act intelligently – meaning they can make decisions, carry out tasks, and even predict future outcomes based on what they learn from data (Higgins *et al*., 2023).

Artificial neural networks (ANN)- are the advanced, machine learning algorithims that emulate the functionality of human brain, enabling computer programs to “learn” for experiences (Jing *et al*., 2018).

Automation- is the use of technology to perform processes, such as tasks, without human involvement (Arntz *et al*., 2017).

Civil engineering- can be defined as applying scientific and mathematical principles to design, build, and maintain the framework of society, such as physical infrastructure, the built environment, and public works (Raton, 2002).

Construction industry- means the broad conglomeration of industries and sectors which add value in the creation and maintenance of fixed assets with the built environment (Ofori, 2022).

Construction economics- is defined as the study of the financial aspects involved in building projects, including the costs, revenues and profits generated throughout the construction process (Ofori, 2022).

Economy- is the study of how individuals and societies choose to use the scarce resources that nature and previous generations have provided.

Geotechnical engineering- is a branch of civil engineering that explores the designs of foundations and slope stability due to the interaction of soils and structures (Lancellotta, 2009).

Industry- is the organised, large-scale production of goods and services for sale (Lasi *et al*., 2014).

Information and communication technology (ICT)- is the collection of hardware, software, databases, networks used to store, process, and communicate digital information (Nath & Liu, 2017).

Productivity is the measure of output (quantity and quality) produced relative to the resource input used, such as labour, machines, tools, materials, energy, and technology (Aarts *et al*., 2020).

1.4 Assumptions

Main hypothesis: The AI adoption AI has a positive effect on the economics of the South African construction industry.

Sub- Hypotheses

$H1_0$: AI adoption has potential economic benefits and drawbacks on the South African construction industry.

$H1_a$: AI adoption has no potential economic benefits and drawbacks on the South African construction industry.

$H2_0$: AI adoption impacts productivity, costs, and employment in the South African construction industry.

$H2_a$: AI adoption does not impact productivity, costs, and employment in the South African construction industry.

$H3_0$: AI adoption in the South African construction industry has ethical and societal implications.

$H3_{a;}$: AI adoption in the South African construction industry has no ethical and societal implications.

$H4_0$: There are barriers to using AI in Civil engineering projects in South Africa.

$H4_a$: There are no barriers to using AI in Civil engineering projects in South Africa.

1.5 Organisation of the study/ thesis

1.5.1 Field of study

Field of study in research is a term often used to refer to an area of knowledge or expertise. For example, according to Rosenfield (1992), the Social Sciences are a comprehensive field of study in research, incorporating topics such as psychology, sociology, economics, law, anthropology, and education. The field of study also includes disciplines such as political science and public administration, international relations, demography, and physical and biological sciences. Additionally, Rosenfield, (1992) suggests that the field of study in research is not limited to any one country or region but encompasses global perspectives on the topics it encompasses. The research in this study will be based on the use and benefits of AI in the South African construction industry.

1.5.2 Sector/ Industry/ Business under assessment

A sector is a wide area of the economy determined by a standard set of characteristics (Raza *et al*., 2021) An industry is a group of businesses or organisations related to their primary business activities (Raza *et al*., 2021). Business refers to any activity for profit, including all the processes involved in organizing, managing, and assuming the risks of a business venture (Raza *et al*., 2021). The three terms are closely related, but each has a distinct meaning and purpose in research. In line with the descriptions, the application of AI-based technology in the construction and civil engineering industry within SA will be the exclusive focus of this research, as highlighted by this proposal. This is a sensible restriction, given that the proposed project will be the author's final product.

1.6 Geographical demarcation

Geographical demarcation is a method used in research to define regions or specific locations to analyse variables. It is essential to demarcate a research area to create a reliable and accurate evaluation method. For example, when studying the effects of climate change on a specific region, it is necessary to create an exact region to study, so the data is reliable, and the results are accurate (Tiwari & Chatterjee, 2011). This demarcation limits the scope of the study to a specific geographical area, allowing the researchers to access local data, compare the differences between regions, and determine the probability of predicted outcomes (Tiwari & Chatterjee, 2011).

Additionally, it helps to ensure that the characteristics of the different locations considered, such as population size and climate, enable comparison between locations (Tiwari & Chatterjee, 2011). The geographical demarcation for this study will be limited to only the construction and civil engineering industry of SA.

1.7 Layout of chapters

The study will consist of the following chapters:

Chapter 1: Introduction

Define the Problem

Purpose of the Study

Research Questions

Significance of the Study.

Definition of Terms

Delimitations of the Study

Assumptions.

Organisation of the Study/ Thesis

Chapter 2: Review of Related Literature and Research

It begins with a listing of the subsections of the literature review.
Use of frequent headings to help readers follow my organisation.
Concludes with a short summary.

Chapter 3: Methodology

Begins with a paragraph explaining the purpose of this chapter.

Purpose of the Study

Research Questions

Review of Related Literature and Research– summary

Method - research framework

Data Collection - show how your data collection addresses each research question)

Role of the Researcher (Optional - if I am performing qualitative analysis, it should explain my role, how I interacted with the participants, my background, etc).

Data Analysis - Describe: show the data analysis addresses each research question.

Final transition paragraph, such as:
Chapter 3 has presented the methodology for collection at data for this study,
Chapter 4 presents research findings and Chapter 5 presents conclusions,
discussion, and recommendations for the future research.

Chapter 4: Findings

Begin with a paragraph orienting the reader to the chapter (because some readers will jump to this location in the thesis/ dissertation and not read the earlier chapters) Present your findings in a logical order, with tables and figures as needed and with frequent use of headings to help readers follow your organisation.

Present quantitative findings.
Conclude with a summary of the findings, and a transitional paragraph, such as: 'Chapter 4 has presented qualitative and qualitative research findings addressing the four research questions of this study.

Chapter 5: Summary, Conclusions, Discussion, and Recommendations

Begin with a paragraph orienting the reader to the chapter (because some readers will jump to this location in my thesis/ dissertation and not read the earlier chapters).

Summary - like the beginning of chapter 4, including purpose of the study, research questions, summary of the literature review, summary of the methodology, plus a summary of the findings.

Conclusions - My conclusions about what the data means - the most important critical thinking insights revealed by your data.

Discussion - In this section, discuss each of your conclusions or major findings. Summarize each one BRIEFLY, but do not stop there. Showing conclusions/ findings compare to another previous research and discuss why each is important. This is where I as a researcher present what I have learned from your research.

Recommendations for Practice - Provide a list of several things that teachers, researchers, administrators, etc.
Suggestions for further research Conclusion - my final thoughts.

1.8 Summary

This chapter introduces the study's background, research problem, objectives, research questions, and relevance. The context of the problem, specifically AI in construction, and its associated factors were discussed. With these foundations established, the next chapter examines existing literature on AI in construction.

Chapter 2

2 Literature review

This chapter helps to understand the existing research and debates relevant to a particular topic or area of study and presents that knowledge as a written report. It helps build knowledge in the field, discusses essential concepts, research methods, and experimental techniques, and gains insight into how researchers apply these concepts to real-world problems. It highlights gaps in the existing research, which the article then addresses through new research. It also establishes the researcher's credibility, illustrates the importance of a particular problem in a field, identifies a gap in the knowledge of a particular subject, and defines key terms and ideas used in a specific field.

2.1 Introduction- AI in construction

Adopting Artificial Intelligence (AI) in the South African construction industry can significantly affect the industry's economics. The construction industry is a significant contributor to the South African economy, and adopting AI can lead to increased productivity, efficiency, and cost savings (Bag *et al.,* 2021; Newman *et al*., 2021). However, adopting AI in the construction industry requires significant technological and infrastructure investments (Bag *et al.,* 2021; Rauch *et al.,* 2019). The cost of implementing AI can be a barrier to adoption, especially for SMMEs (Rauch *et al.,* 2019). Therefore, adopting AI in the South African construction industry can positively and/ or negatively impact the industry's economics, especially for SMMEs.

The construction industry is a labour-intensive industry, and the adoption of AI can lead to the displacement of workers (Parschau & Hauge, 2020). Moreover, adopting AI in the construction industry can lead to job losses, especially for low-skilled workers (Parschau & Hauge, 2020). However, AI can create new job opportunities in the latest technological value chain (Parschau & Hauge, 2020).

The research question concerning organisational factors of AI adoption in the South African construction industry remains to be clarified (Rauch *et al.,* 2019). However, the impact of AI in South Africa is not a myth, and there is a threat of job losses in adopting AI (Parschau & Hauge, 2020). Nevertheless, AI can create more jobs in the new technological value chain (Parschau & Hauge, 2020). Therefore, it is essential to investigate the effects of AI adoption on the South African construction industry economics.

The construction industry is under-digitized, and adopting AI can increase productivity, efficiency, and cost savings (Bag *et al.,* 2021; Newman *et al*., 2021). AI can automate repetitive tasks, reduce errors, and improve safety (Tyagi *et al.,* 2021). AI can also provide real-time data analysis, which can help in decision-making and project management (Tyagi *et al.,* 2021). Therefore, the adoption of AI in the South African construction industry can have a positive impact on the industry's economy.

In conclusion, adopting AI in the South African construction industry can positively and negatively affect the industry's economy. AI can increase productivity, efficiency, and cost savings but requires significant investment in technology and infrastructure. AI can also lead to job losses, especially for low-skilled workers, but it can create new job opportunities in the latest technological value chain (Parschau & Hauge, 2020). Therefore, it is essential to carefully consider the impact of AI adoption on the South African construction industry's economics and to find a balance between the benefits and costs of AI adoption.

2.2 Overview of AI in construction

AI is making significant strides in the construction industry, transforming traditional processes and revolutionising project planning, design, and execution (Pan and Zhang, 2021; Khaleel *et al*., 2023). AI technologies such as machine learning, computer vision, and natural language processing are being integrated into various aspects of construction to improve efficiency, safety, and accuracy (Rayhan, 2023; Wu *et al*., 2022).

One of the key applications of AI in construction is in project planning and design. AI-powered software and algorithms can analyse historical data, project specifications, and market trends to generate accurate cost estimates, optimise project schedules, and identify potential risks and challenges (Mostafa *et al*., 2023). AI enables construction professionals to make informed decisions and deliver projects on time and within the budget (Zhu *et al*., 2022; Attaran & Celik, 2023).

On-site operations also benefit from AI technologies (Ghadiminia and Saeidlou, 2023). Drones with AI algorithms can conduct site inspections, survey land, monitor progress, minimise real-time analysis, and provide real-time data to project managers (Patel *et al*., 2021). AI-powered robots can assist in tasks such as bricklaying, concrete pouring, and material handling, thereby reducing labour-intensive work and improving productivity (Wang *et al*., 2023). Additionally, AI can analyse data from sensors and IoT devices to predict equipment failures, enabling proactive maintenance and minimising analysis downtime (Soori *et al*., 2023).

AI also enhances communication and collaboration among stakeholders in the construction industry (Regona *et al.*, 2022; Abioye *et al*., 2021). AI-powered project management tools facilitate real-time collaboration, document sharing, and instant communication among architects, engineers, contractors, and clients (Pan and Zhang, 2021). This streamlines decision-making processes, reduces errors, and improves overall project efficiency.

Furthermore, AI drives innovation in building designs and sustainability. AI algorithms can analyse building performance data and provide insights into energy optimisation, reducing energy consumption and environmental impact (Himeur *et al*., 2022). AI can also assist in designing structures that are resilient to natural disasters and climate change, thereby ensuring the long-term sustainability of construction projects (Argyroudis *et al*., 2022).

Safety is a critical aspect of the construction industry, and AI plays a vital role in improving safety measures. AI-powered computer vision systems can monitor construction sites for potential hazards, identify safety violations, and alert workers in real-time (Patel *et al*., 2021). AI helps prevent accidents, reduce risks, and ensure compliance with safety regulations (Schuett, 2022).

AI is transforming the construction industry by revolutionising project planning, enhancing on-site operations, improving communication and collaboration, driving innovation in building design, and enhancing safety measures (Mostafa *et al*., 2023). Integrating AI technologies into construction processes enables construction companies to streamline operations, reduce costs, improve productivity, and deliver projects more efficiently (Pan & Zhang, 2021). AI's impact of AI on the construction industry is expected to grow, paving the way for a sustainable, technologically advanced future.

2.3 AI in construction- a global perspective

AI is creating waves in the construction industry globally. Countries worldwide recognise AI's potential to revolutionise construction processes and actively incorporate AI technologies into their projects (Pan & Zhang, 2021). In Europe, countries such as the United Kingdom and Germany are leading ways to adopt AI in construction (Buchholz, 2020). AI-powered software optimises project planning, improves resource allocation, and enhances risk management. Additionally, AI algorithms are employed to analyse building performance data and optimise energy consumption, aligning with the region's focus on sustainability.

In the United States, AI is gaining traction in the construction industry (Buchholz, 2020). Construction companies utilise AI-powered drones and robots for site inspection, surveying, and data collection (Regona *et al*., 2022). AI algorithms are also used to analyse massive amounts of data to identify patterns and make accurate predictions, enabling better decision-making and reducing project delays.

In Asia, countries such as China and Japan embrace AI in construction to address infrastructure needs (Buchholz, 2020). AI technologies are used to automate construction processes, improve safety, and enhance productivity. For instance, China invests heavily in AI-powered construction equipment and robotics to increase efficiency and reduce labour costs (Yang *et al*., 2021).

In the Middle East, countries such as the United Arab Emirates and Saudi Arabia are leveraging AI to drive innovation in construction (Dabdoub *et al*., 2022). AI-powered tools are used to optimise project schedules, monitor progress, and ensure compliance with safety regulations (Kumar, 2021). Additionally, AI is integrated into building design to create intelligent, sustainable structures that withstand extreme weather conditions.

Africa has also witnessed the adoption of AI in construction (Kanyilmaz *et al*., 2022). AI-powered software was used for project management, cost estimation, and risk analysis. This enables construction companies to deliver projects more efficiently and within budget. Furthermore, AI is utilised to improve safety measures and enhance the quality of construction projects. AI in construction is not limited to a specific region but is gaining prominence on a global scale. Countries across Europe, the Americas, Asia, and Africa recognise the potential of AI to transform the construction industry. By harnessing the power of AI, construction companies can improve project planning, enhance on-site operations, optimise resource allocation, and drive innovation in building design. As AI technology continues to evolve, its global adoption in construction is accelerating, leading to more efficient, sustainable, and technologically advanced construction projects worldwide.

The merits of the 4IR are indisputable. AI is an instrumental section of the 4IR, and its adoption has resulted in industry productivity growth (Mhlanga, 2021). It has also assisted in driving innovation in science and engineering (including civil engineering) (Damioli *et al.,* 2020). AI is the philosophy and advancement of computer systems capable of executing activities ordinarily demanding human intellect, it also scrutinises by what method to capture and comprehend the logical conduct of computers, or in what way to answer predicaments with the use of computers that necessitate interoperability (Paschek *et al*., 2017). AI is the philosophy and advancement of computer systems capable of executing activities ordinarily demanding human intellect, it also scrutinises by what method to capture and comprehend the logical conduct of computers, or in what way to answer predicaments with the use of computers that necessitate interoperability (Paschek *et al*., 2017).

AI uses computer algorithms, machine learning (ML), neural networks, and the internet to execute tasks traditionally executed by humans with high precision and repeatability (Galbusera, Casaroli, and Bassani, 2019). For example, Geotechnical engineering is a branch of Civil Engineering that deals with the scientific behaviour of the earth and its materials (Onyelowe *et al.*, 2023). This industry sector is also benefitting from AI to complete complex tasks in minimal amounts of time at a reduced cost.

The world is fast adopting AI technologies to solve day-to-day problems. This is because the success of modern societies has grassroots in technological advancements in community, education, and industry (Moloi & Mhlanga, 2021). AI has been helpful in expeditiously solving complex non-linear relationships, which would have otherwise been a mammoth task to execute using tractional methods (Baghbani *et al.,* 2022).

Research has shown that adopting AI in developed countries will increase productivity in the industry (Buchholz, 2020). This is relevant to SA as a fast-developing country, and models can be created with guidance from developed countries. Developing countries, also known as Less Developed Countries (LDC(s), have lower industrialisation, infrastructure, and overall economic development levels than more advanced countries (Adamu *et al*., 2022). Developing countries often face challenges such as poverty, limited access to education and healthcare, high unemployment rates, and inadequate governance systems (Fagbemi 2021). Developing countries are typically characterised by a large agricultural sector, a high population growth rate, and reliance on natural resources (Parker *et al*., 2019). They often seek to improve their economic and social conditions through various strategies, such as attracting foreign investment, promoting technological advancements, and implementing policies to reduce poverty and inequality. Figure 2.1 below shows the projected growth due to the adoption of AI in developed countries.

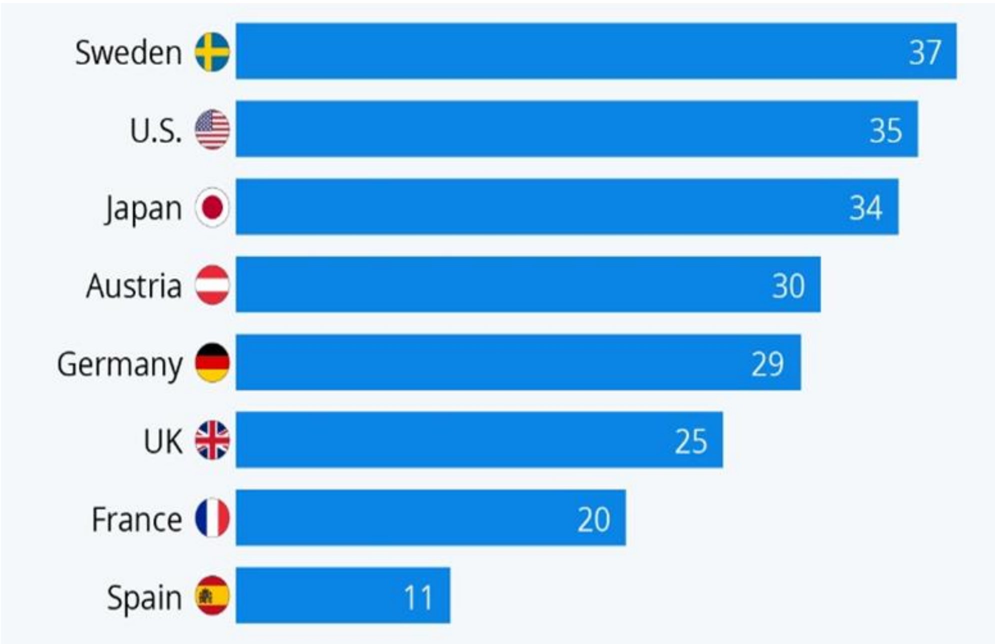

Figure 2. 1 Projected Increase in Productivity due to AI in Selected developed countries (%), adopted from Buchholz (2020).

However, Petropoulos (2018) argued that the advent of digitisation (which later evolved to AI and other 4IR technologies) has led to the displacement of workers. The studies point out that a new demand for skilled labour arises after a technology is implemented in an industry (Makaula *et al.,* 2021; Petropoulos, 2018). Therefore, in conjunction with employers, policymakers must put policy frameworks that allow employees' skills development to remain relevant in the continuously evolving industry around automation and AI (Karr *et al.,* 2020).

2.4 AI in construction- developing countries including Africa.

The construction industry worldwide is rapidly changing with technological innovation, particularly AI (Regona *et al*., 2022). However, construction organisations in developing countries such as Africa still need to recognize the need to adopt emerging digital innovations such as AI to improve the built sector's performance (Windapo, 2021). Despite its vast potential, the adoption and implementation of AI in Africa faces several challenges, including the need for more relevant technical infrastructure and digital connectivity (Aruleba & Jere, 2022).

AI presents countless avenues for the public and private sectors to optimize solutions to the most crucial problems facing the continent today, especially for struggling industries (Ndungu & Signé, 2020). South Africa has led the continent to adopt AI with a robust ecosystem, including numerous technology hubs and research groups (Blankson & Anani-Bossman, 2023). However, AI adoption in Africa is still in its early stages, and there is a need for more collaboration between individual national governments and AI innovators, as well as between national stakeholders and the international community (Adeshina & Aina, 2023).

One study proposed a framework for implementing responsible AI in Anglophone Africa, built around three pillars: governance, capacity building, and Research and development (R&D) (Qondi, 2023). Greater use of AI in scientific research in Africa will bring numerous benefits, deepening African science and broadening global research agendas. (Youssef & Kevin, 2020). Professor Alan Blackwell's vision is to build an AI that works in sub-Saharan Africa (Jonathan, 2019).

In low-resource contexts, there needs to be more collaboration between individual national governments and AI innovators, as well as between national stakeholders and the international community. Fostering stakeholder buy-in across various sectors of AI use is also needed, especially in the public sector, where clear guidelines for AI procurement could help understand where its use is not required (Ade-Ibijola & Okonkwo, 2023). Ten vital enabling technologies drive Africa's digital economy, including that of AI. However, several structural challenges undermine the rapid adoption and implementation of AI on the continent, such as inadequate basic and digital infrastructure (Youssef and Kevin, 2020).

In conclusion, AI adoption in the construction industry remains to be determined, particularly in developing countries. The benefits of AI adoption are numerous, and there is a need for more collaboration between individual national governments and AI innovators, as well as between national stakeholders and the international community. Greater use of AI in African scientific research will bring numerous benefits, deepening African science, broadening global research agendas, etc. However, AI adoption in Africa faces several challenges, including a more relevant technical infrastructure and digital connectivity.

2.5 AI in construction-SA.

A theoretical assessment of the implementation of AI for an improved learning curve on construction in South Africa was conducted (Phaladi *et al*., 2022a). The study highlighted the potential of AI to improve productivity, performance, and safety in the construction industry in South Africa. Another study aimed at developing a framework for AI in construction management. The study reviewed the literature on AI in construction project management and proposed a framework for AI adoption in the South African construction industry (Makaula *et al*., 2021). The study showed that AI can be used in the planning, design, and simulation of construction projects. Furthermore, the study revealed that AI can be employed for advanced project execution phases of construction as well as in sourcing materials and modularisation of high-end and specialized construction materials and modules. An article discussed the potential of AI in the construction industry in South Africa. It highlighted the benefits of harnessing robotics and intelligent machines to automate routine tasks, improve safety, and optimize resource management. Overall, these studies suggest that AI has significant potential to improve productivity, performance, safety, and resource management in the construction industry in South Africa. However, there is a need for further empirical studies on AI adoption and implementation in the South African construction industry.

2.6 AI in construction economics globally and SA

AI has been receiving increasing attention across various industries, including construction (Darko *et al.*, 2020). The potential impact of AI in construction economics is immense, as it can revolutionize the cost management process, enhance operational efficiency, and improve project delivery time (Abioye *et al.*, 2021).

One of the keyways in which AI can impact construction economics is through improved cost management processes. According to Pan and Zhang (2021), AI-based cost estimation tools can analyse large amounts of data in real-time, making predicting and managing project costs easier. This can lead to more accurate budgeting and forecasting, reducing project overruns and lowering project costs. Similarly, Parsamehr *et al.* (2023) noted that AI-based scheduling tools could assist with real-time monitoring of project schedules and identify potential bottlenecks or delays, helping project managers make more informed decisions.

The use of AI in construction can lead to increased operational efficiency. According to Jung *et al.* (2021), AI-powered drones can be used for site surveying, mapping, and monitoring, significantly reducing the time and resources required for traditional site surveys. Equally, Durbhaka (2021) noted that AI-based predictive maintenance can reduce downtime, increase equipment lifespan, and ultimately lower operating costs. These applications of AI provide notable benefits to construction economics.

Another potential benefit of AI in construction is increased project delivery time. According to Pan and Zhang. (2021), using AI-powered tools for quality control can improve construction speed and reduce the time required for review and inspection. Additionally, Durbhaka (2021) noted that AI could enable predictive modelling of potential issues during a project's lifecycle, which can help project managers identify and address any potential problems before they become delayed, ultimately reducing project timelines.

However, some researchers have noted potential drawbacks to the widespread use of AI in construction. For example, Pan and Zhang (2021) indicated that reliance on AI-powered tools might decrease reliance on intuition and subjective decision-making in the construction industry. Further, Pan and Zhang (2021) pointed out that a lack of human oversight might lead to unintended consequences or mistakes. Therefore, construction industry practitioners must apply caution and a measured approach when implementing AI in construction.

The study supports that the impact of AI on construction economics is vast and varied. According to Hire *et al*. (2021), there are potential economic benefits of AI in the Africa construction industry, such as improved cost management, operational efficiency, and reduced project timelines, are evident. While some researchers have hinted at potential drawbacks, the literature indicates that integrating AI in construction will likely become increasingly prevalent as its positive impact becomes clear.

2.7 AI in sustainability of construction global and SA

Civil engineering environments generally involve working in hazardous environments such as underground, underwater, and extreme weather conditions such as extreme heat and cold. These environments are dangerous to humans and extremely expensive in terms of project planning, labour, and machinery costs (Baker *et al.,* 2020). By applying AI in prospection and planning, it is possible to increase efficiency drastically because no energy is wasted in unnecessary drilling and earth-moving exercises. AI-based systems would have pinpointed the working area beforehand with high levels of accuracy. AI-based mathematical models can identify mineral occurrence and purity such that by the time a civil process physically commences, the engineers and technicians know exactly where to drill and how much energy is required (Jooshaki *et al.,* 2021). Robots, crawlers, and smart thermal cameras can also be used to perform work traditionally performed by human beings in civil engineering.

Sustainability and environmental impact are essential areas of concern as far as the 4IR, and AI are concerned. Therefore, sustainability and ecological impact are necessary when implementing AI technologies in the civil engineering industry. Studies show that AI infrastructure, such as computers and servers, use high amounts of electricity, resulting in a larger carbon footprint, if the country relies on power stations powered by fossil fuels (Yigitcanlar *et al*., 2021). However, AI is also the key driver in developing smart cities, characteristic of a low carbon footprint. It is used to optimize resource management with the net effect of a collectively lower energy consumption figure (Bokhar & Myeong, 2022). Solar energy can power computers and support infrastructure with AI, thus keeping environmental impact minimum (Queiroz *et al*., 2021). Although extremely useful, AI comes with its fair share of challenges. For example, computing infrastructure that supports AI is expensive (ITU, 2018).

Also, the AI programme is only as good as the mathematical and physical models feeding it. For example, soil and rock mechanics exhibit a high degree of variability, posing extreme challenges regarding mathematical modelling and predicting their behaviour (Shahin *et al.*, 2009). As a result, if an inaccurate model is supplied to the AI algorithm, it will return incorrect results. However, neural networks which get better at performing tasks due to repetitive computation are being employed, which will result in more capable AI systems.

2.8 Application of AI in construction-global and SA

According to IrimiaDiégues *et al.* (2014) and Kutschenreiter-Prasskiewics (2018), risk management is a systematic process for identifying, analysing, and responding to risks. Risk demands careful consideration because it might affect the "cost-benefit analysis" in the entire creation of a project, as well as the necessity, costs, and length (Irimia-Diégues *et al.,* 2014). Risk management is applied in all project lifecycle phases to reach project goals (Rafindadi *et al*., 2014).

Project risk management is most effective when started early in the project life cycle; it includes methods, tools, and techniques that help the project manager take advantage of constructive acts and reduce the chance of consequences of hostile actions (Kutschenreiter-Prasskiewics, 2018). By examining the project's at-risk parameters, AI aids in "quantitative risk management," "machine learning" and "Monte Carlo simulation" assist in "risk appraisal and simulation," and "fussy logic" is used to assess risks in infrastructure projects to model "probability distributions" (Johnsonbabu, 2017).

Through real-time project data analysis, AI can warn the project manager of potential risks (Johnsonbabu, 2017). AI has brought innovation to risk management, enhancing understanding of unstructured data, and providing a more flexible automated analytics approach by synthesising approaches (Dooley, 2017). According to Dooley (2017), most specialised AI-driven applications focus on fields that may use AI to examine massive amounts of data and identify instances of behaviour.

AI can assist organisations at various stages of the risk management process, including "identifying risk exposure," "measuring," "estimating," and "assessing its effects." It can also help in selecting an appropriate risk reduction strategy and learning about tools that can facilitate risk transfer (Sanford & Moosa, 2015), cited in (Asis & Dowling, 2018).

2.9 Barriers of adoption of AI in construction-global and SA

The utilisation and implementation of AI technology within the civil engineering industry of SA has mainly been hindered by a lack of investment and knowledge. In an empirical study, (Popenici & Kerr, 2017) discovered that 'there is a need to invest in education, training and development and also a greater understanding of AI, what it can do and how it can be utilised.' Indeed, this lack of investment in AI infrastructure and staff education has entrenched a culture of suspicion and wariness towards the possibilities of digital transformation in the sector. Consequently, the industry is at a crossroads, with the ability to innovate and improve dependent upon the ability to invest in suitable sources and required training. Another critical barrier to adopting AI is the general need for digital skills in the South African civil engineering industry. Indeed, a recent review of the impact of AI on the sector by Lerner and Stern (2018) argued that 'the speed and potential disruptive power of AI are of concern, especially among established firms, given the scarcity of in digital house skills." This lack of digital capability has created a disconnect between the senior civil engineering professionals unfamiliar with AI and the younger generations of postgraduate engineers, who possess sufficient digital expertise to help drive innovation (Lunevich, 2023). This schism has made it difficult for the sector to accept innovations and technological shifts that could significantly alter how civil engineering operates in SA.

The inadequate funding infrastructure is a further hindrance to the effective adoption of AI in the country. As Gwagwa *et al*. (2021) highlighted, due to 'the lack of venture capital in SA, AI projects have been slow to be developed or implemented'. This is compounded by the complexity of the South African civil engineering market, where the domestic focus is on the infrastructure of construction, in stark contrast to the international market's focus on more innovative applications of technology, such as driverless cars (Sutherland, 2020). Furthermore, the current rigid regulatory framework has also limited the development of AI projects. This issue was reiterated by Borgogno & Colangelo, 2019 who concluded that 'the absence of a regulatory system which promoted the flourishing of AI on the domestic market has impeded the effective introduction of the technology'. Overall, the lack of adequate investment, adequate digital skills and complex funding infrastructure have helped adopt and implement AI in the South African civil engineering industry. Furthermore, this is compounded by the current regulatory framework, which has proven to be a significant hindrance to the sector's ability to embrace and adopt AI as an integral part of its operations. To successfully drive industry transformation and ensure that the country can take advantage of the many benefits that AI can offer, the government and private sector must look to address these issues.

2.10 Summary

This literature review has shown that AI in construction and various facets within construction, both globally and in SA, are necessary. AI has a beneficial impact on the economy, productivity, and sustainability. The next chapter presents the method adopted in this study.

Chapter 3

Research methodology

3. Introduction

This chapter discusses the research methodology employed in this study to meet the research objectives. The population sample, study design and the geographical area of the study are also explained. Furthermore, the chapter includes a description of the instrument used in collecting the data, including methods administered to maintain validity and reliability to evaluate the societal and ethical issues, approaches, barriers, potential benefits and ways of adopting AI in the South African construction industry.

3.1 Research process

Saunders *et al.* (2019) argue that the achievement of desired objectives requires the execution of research activities, which involves the collection and analysis of data to uncover various occurrences. Considering the research process, it is imperative to acknowledge the importance of establishing a clear research approach. Saunders *et al.* (2019) propose the utilisation of the research process onion as a framework to elucidate the factors influencing the choice of data-gathering for gathering data in research.

Scholars have identified that the research process onion encompasses five distinct levels. These layers include the concept of the study, research strategy, methodology for research, time prospects, and collecting data tools (Saunders *et al.,* 2019). The utilisation of the research process onion proposed by Saunders *et al.* (2019) is employed in the development of this research technique. The collected data will offer a comprehensive theoretical foundation for the introduction of the research issue and furnish the necessary resources for the development of the study's conceptual model, as depicted in Figure 3.1.

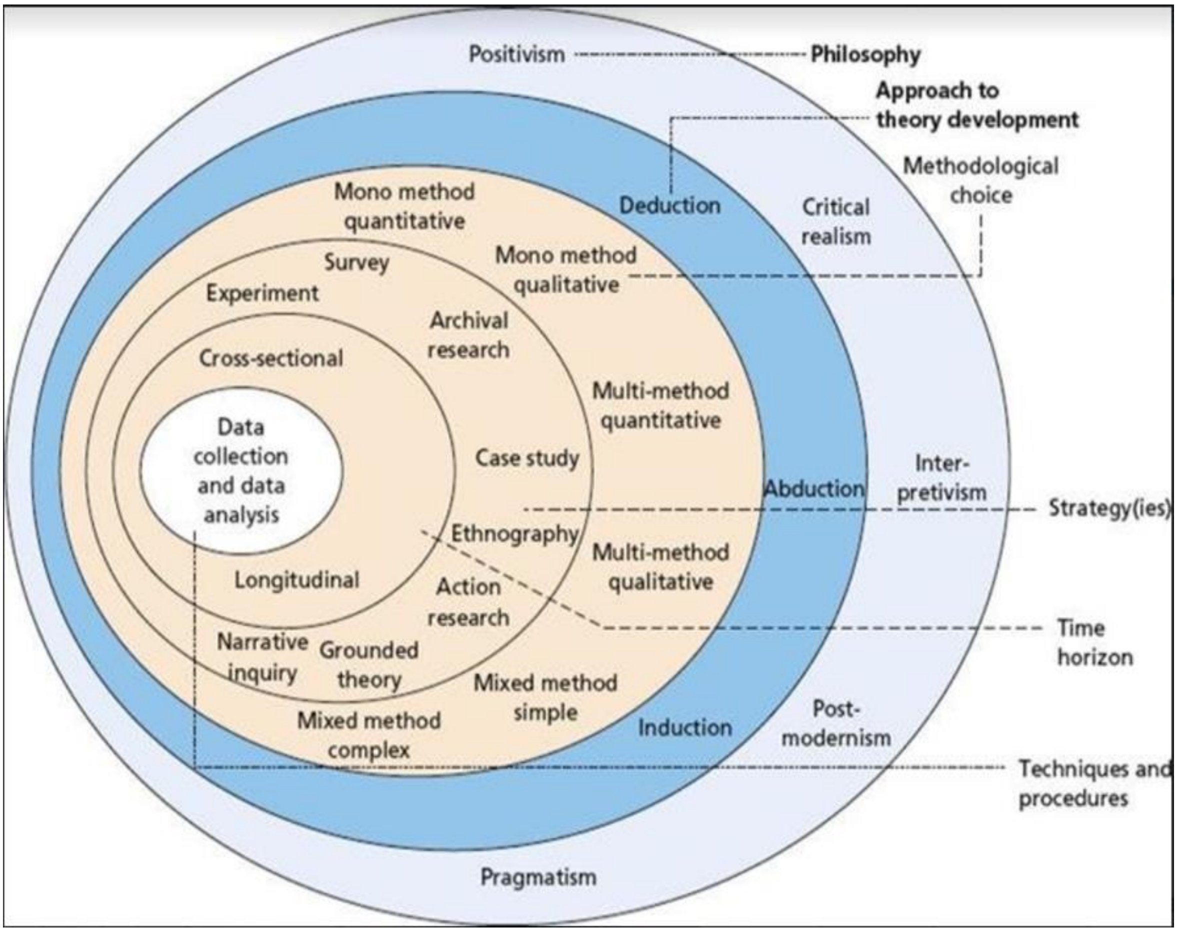

Figure 3. 11: ***Research Onion Ring*, adapted from Saunders *et al*., (2019)**

3.2 Empirical Study

3.2.1 Research Paradigm/ Philosophy

Within the realm of elucidating, theorising, and classifying research methodologies, the most foundational approach lies in the examination of said methodologies through the lens of their underlying philosophical principles (Clarke, 1998). The examination of research methodologies from a philosophical standpoint entails the consideration of fundamental principles that underpin various aspects of our world. These principles encompass the mind, substance, actuality, logic, truth, the nature of learning, and how it is validated (Walliman, 2021). The classification of research philosophies encompasses three distinct categories, namely positivism, interpretivism, and realism.

The lineage of positivist thought can be traced back through the annals of intellectual history, characterised by a rich tapestry of evolution, rebuttals, reiteration, and reassessment. The underlying principle that underpins positivist thought is the belief in the existence of an objective truth that exists independently of human actions, thereby precluding the possibility of it being merely a product of human imagination. According to the tenets of positivism, the pursuit of scientific inquiry serves as the most effective means to attain veracity, enhance our comprehension of the world, and ultimately enable us to forecast and govern its intricacies.

In the realm of cosmic operations, it is imperative to acknowledge that the universe adheres to the principles of causality and determinism, thereby exhibiting a distinct nature when subjected to the scientific method. In the realm of positivism, it can be argued that a mechanistic or mechanical nature fundamentally characterises science. In the realm of business administration, methodical reasoning serves as a fundamental tool for both speculation and theory testing. Based on the empirical findings, it is possible to ascertain the congruence between a particular approach and the observed facts. If the approach does not align with the empirical evidence, it becomes imperative to make appropriate revisions to the theoretical framework. This iterative process of refinement ensures a more precise prediction of real-world phenomena, as advocated by Easterby-Smith *et al*., (2008). Positivists espouse the philosophical stance of empiricism, wherein the pursuit of scientific knowledge is anchored in the meticulous processes of observation and measurement. The primary approach of the scientific method entails systematic experimentation aimed at the recognition and comprehension of laws by means of direct manipulation and observation (Trochim, 2000).

However, it is important to note that this approach has inherent limits for doing research, as it necessitates a predetermined and structured research design. In accordance with the underlying assumptions of this technique, researchers possess the capacity to influence the approach via the lens of their personal views or maintain objectivity. To achieve generalisations from the results, it is advisable to employ large samples, as the complex nature of the subject under study necessitates several measurements.

Hatch and Cunliffe (2006) believe that the interpretive/ constructivist ideology can be succinctly characterised as being opposed to positivism. Interpretivism is sometimes characterised as a model that employs inductive reasoning or theory construction. According to Denzin and Lincoln (2003), interpretivists hold the belief that several realities might exist, and that all knowledge is inherently connected to and shaped by the one who acquires it. Hatch and Cunliffe (2006) argue that interpretivism is characterised by a collaborative approach aimed at comprehensively understanding and deriving meaning from many perspectives. Researchers employing this paradigm utilise these insights to conclude their research endeavours.

According to Saunders *et al*. (2009), the findings of such research are typically not generalised but rather concentrate on comprehending the meanings and perspectives of participants within their specific situations. In addition, it is crucial to examine the cognitive and affective aspects of individuals, as well as their interpersonal communication strategies (Easterby-Smith *et al*., 2008). The nature of this study is regarded as being more qualitative as it places greater emphasis on language and the collection of subjective data (Eriksson & Kovalainen, 2008). Researchers adhering to this theoretical framework are advised to thoroughly consider any potential bias that may inadvertently arise in the study because of its subjective nature and the intimate connections between researchers and their participants.

Blaikie (1993) asserts that realists endeavour to comprehend and quantify these mechanisms while acknowledging the necessity for such processes to align with empirical facts. Hatch and Cunliffe (2006) posit a notion that events might occur independently of being perceived, elucidating a conceptual framework wherein observable occurrences are governed by concealed mechanisms that elude the casual observer.

In this study, the researcher will adopt a positivistic research paradigm that will be used to test the hypothesis when examining the relationship between both variables of the study.

3.2.2 Research Approach

The methodological literature presents two distinct research methodologies, namely deductive and inductive approaches. The deductive research approach, alternatively referred to as the top-down strategy, involves the development of a thorough theory prior to formulating a concise hypothesis. Subsequently, researchers collect an ample amount of data pertaining to the topic matter, which is subsequently subjected to analysis to substantiate or refute the formulated hypothesis. Therefore, it may be argued that this technique tends to align its application and development, as noted by Roschelle (1992).

The inductive research approach might be considered as an inverse of the deductive technique. This methodology involves conducting a detailed examination of a specific aspect of a broader study topic to conclude. The examined portion may appear insignificant in isolation, but it finally demonstrates its essentiality to the research topic (Hatch, 2002). This methodology commences by scrutinising the observations and facts pertaining to the segment, followed by evaluating it within the broader context (Denzin & Lincoln, 2003). The methodology involves transitioning from a particular segment of the overarching research theme to the broader subject matter, culminating in a final determination.

The present study employed a deductive method. During the development of the conceptual framework for this dissertation, a thorough critical review was conducted.

3.3 Methodological Choice

Saunders *et al*. (2009) identify two primary research methodologies, namely mono and multiple approaches. The mono method involves the gathering and analysis of a single set of data, which can be categorised as either quantitative or qualitative. Quantitative data-gathering approaches and data analysis involve the generation or utilisation of numerical values (Bryman & Bell, 2003). On the other hand, qualitative data pertains to the utilisation of any data collection method, such as interviews, or data analysis methodology, such as data categorisation, that produces or employs non-numerical data (Saunders *et al.,* 2009).

In contrast to the singular method, the many methods employ a variety of data-gathering techniques and analytic procedures (Saunders *et al.,* 2009:152; see figure 3.1). This mini-dissertation, as previously said, employed a method of quantitative analysis and was conducted using a mono-quantitative methodology.

3.4 Research Strategy

Quantitative research entails the systematic collection of numerical data, which is subsequently subjected to statistical analysis techniques. Quantitative analysis often employs two prevalent methodologies, namely survey and experiment strategies (Yin, 2006).

Surveys encompass the process of gathering data from a subset of persons through the administration of a questionnaire or an interview (McLafferty, 2016). Surveys may be administered through face-to-face interviews, telephone conversations, or internet platforms. Surveys can gather data pertaining to a wide range of subjects, encompassing attitudes, views, behaviours, and demographic characteristics. According to Yin (2006), surveys have the potential to be designed in three different ways: descriptive, correlational, or explanatory.

Experiments encompass the deliberate manipulation of one or more variables with the aim of ascertaining their impact on a specific outcome of interest (Festing, 2006). Experiments are a valuable method for establishing causal relationships between variables. Experiments may be carried out either within a controlled laboratory setting or in a natural environment, commonly referred to as the field. Researchers have the option to design experiments in three different ways: between subjects, within-subjects, or mixed (Cahenzli *et al.,* 2021).

Both surveys and experiments include their own set of advantages and limitations. Surveys are a convenient method of data collection that allows for the administration of questions to a substantial sample size of individuals. Nevertheless, it is important to acknowledge that surveys are susceptible to response bias, which can potentially compromise their ability to provide an accurate representation of the target population. A higher level of rigour characterises experiments and can establish a causal relationship between variables. Nevertheless, there are instances where doing trials may not be practical or morally justifiable (Crane *et al*., 2020).

In summary, survey and experiment tactics are two often employed methodologies in the realm of quantitative research. Surveys encompass the process of gathering data from a subset of persons through the utilisation of questionnaires or interviews. Conversely, experiments entail the deliberate manipulation of certain factors to ascertain their impact on a particular result of interest. Both methodologies possess their own set of advantages and disadvantages, and the selection of a particular approach should be contingent upon the research inquiry and the practicality of the chosen method. A survey approach will be employed in this investigation.

3.5 Time Horizon

Time horizon, also called the “long run”, is an integral aspect of research. It is a concept that has been discussed in literature for decades and continues to be an essential consideration for researchers in numerous fields (Denscombe, 2017). Research into areas that require strategic decision-making or are impacted by long-term trends needs to be conducted over a more extended period to capture the evolution of the phenomenon being investigated (Bryman & Bell, 2015). The time horizon chosen will depend primarily on the characteristics and properties of the topic and the research being conducted; however, it is typically thought that more prolonged periods are more applicable for drawing valid and reliable research conclusions (Denscombe, 2017). As such, the time horizon should be carefully considered for each research project, ensuring that the period studied is sufficient to capture the dynamics of the chosen topic. Since the study is cross-sectional, assessments will occur over a single period in the short term.

3.6 Study population and sampling (Recruitment)

According to Salkind (2010:1109), a sample refers to a portion of the population that serves as a representative of the full population under investigation. To pick a sample, it is necessary to employ either probability or non-probability sampling processes (Schreuder *et al.,* 2001).

According to Acharya *et al.* (2013), probability sampling involves providing every member of the population with an equal chance of being chosen for inclusion in the sample. By contrast, non-probability sampling is dependent on random selection. The selection process does not ensure equitable opportunities for all members of the population to be chosen.

According to Johnston *et al.,* (2008), sample size refers to the number of participants chosen from the research population to partake in the study, hence constituting the research sample. This research employs a quantitative approach, thus necessitating the utilisation of a probability sampling strategy. According to Hair *et al.,* (2014), it is recommended to achieve a sample size that includes a proportion of 15 respondents for each variable in the survey. The designated sample size for this study was a minimum of 32- 240 respondents with a preference for 120 individuals from the Engineering Council of South Africa (ECSA) and 120 individuals from the South African Council for the Project and Construction Management Professionals (SACPCMP). This allocation aimed to achieve a balanced and representative representation of the construction industry in SA, considering the certification bodies involved. Furthermore, for inclusion in the sample, participants were required to meet two specific criteria: (1) possess a minimum of one year’s experience within the construction business, and (2) have professional registration.

3.7 Data Collection

After determining the study paradigm, methodology, and choice, the researcher proceed to select the data collection technique, which is also referred to as the methodological strategy (Bryman & Bell, 2015:100). Surveys are widely utilised as the primary method for data collection in quantitative research.

Surveys commonly adopt either closed- or open-ended questionnaires as their preferred format (Bryman & Bell, 2011:54). To ensure an organised character, the researcher should predetermine the questions for the questionnaire. Furthermore, when participants have the freedom to complete the survey at their discretion and within their timeframe, it is referred to as a self-administered questionnaire (Kazi & Khalid, 2012).

Due to the inherent characteristics of the research, a methodology employing an online survey approach was implemented, utilising a self-completed survey as the major means of data collection for the present study. Participants were recruited by seeking permission from the ECSA and SACPCMP to distribute the questionnaire to its members on behalf of the researcher. ECSA and SACPCMP membership comprises engineering professionals nationwide who possess valuable insights relevant to this study. By involving ECSA and SACPCMP members, the researcher could access a knowledgeable and diverse group of engineering professionals to gather meaningful data and valuable perspectives for research.

The demographic information section of the questionnaire allowed the researcher to understand better specific background characteristics and patterns, such as age, sex, and education. That information ensured that the data were fair and represented a representative view and perception of the construction sector. Furthermore, it allowed the researcher to obtain a balanced response rate and a diverse participation pool. This will provide detailed insights and a better understanding of the current and future trends.

3.8 Statistical/ Data Analysis

The process of quantitative data analysis encompasses the utilisation of computational and statistical techniques to examine numerical data sets (Baraldi & Enders, 2010). Quantitative analysis employs two primary branches of statistical methodology, namely descriptive statistics, and inferential statistics (Ali & Bhaskar, 2016). Descriptive statistics serves the purpose of providing a concise summary and depiction of the primary characteristics of a given dataset, encompassing key measures such as the mean, median, and standard deviation. In contrast, inferential statistics are employed to conclude a larger population by analysing a representative subset of data (Ali & Bhaskar, 2016).

To conduct a proficient quantitative data analysis, it is imperative to consider both the nature of the data under examination and the objective of the study (Patton, 1999). According to Christenson and Gutierrez, (2016), the initial stage of quantitative data analysis entails the descriptive statistical phase, wherein the data set is summarised and described. This study employs a more in-depth examination to extract valuable insights, including the utilisation of inferential statistics (Bennett & Elman, 2007).

Quantitative research is a research methodology that prioritises the quantification of data gathering and analysis (Russell, 2005). The formation of this technique is derived from a deductive methodology that places focus on the testing of theories influenced by ideologies rooted in empiricism and positivism (Love *et al*., 2002). Quantitative methods play a crucial role within the framework of the data percolation methodology, which encompasses five distinct approaches to analysis. These include qualitative methods, literature reviews, professional interviews, and computer modelling.

In essence, the process of quantitative data analysis encompasses the utilisation of statistical and computer techniques to examine numerical datasets. Quantitative research is a research methodology that prioritises the quantification of data gathering and analysis. It is derived from a deductive approach that emphasises the empirical testing of theoretical frameworks. Quantitative analysis employs two primary disciplines of statistical approaches, namely descriptive statistics, and inferential statistics. The study employed descriptive statistics to conduct a comprehensive examination of the quantitative data.

3.9 Reliability and Validity (Trustworthiness)

Questionnaires are commonly used in quantitative research to collect respondents' attitudes, experiences, or opinions (Sak-Dankosky *et al*., 2014). When employing questionnaires, researchers must consider the concepts of reliability and validity (Roberts & Priest, 2006). The concept of reliability pertains to the degree of consistency exhibited by an indicator, whereas validity concerns the extent to which a measurement accurately captures the intended construct (Higgins & Straub, 2006; Salmond, 2008). In other words, a reliable questionnaire produces consistent results, while a valid questionnaire tests what it claims to measure (Higgins & Straub, 2006).

To ensure the reliability of a questionnaire, researchers can use statistical methods to measure consistency (Salmond, 2008). An illustration of test-retest reliability encompasses the process of presenting an identical questionnaire to the same group of respondents on two separate occasions, followed by a comparison of the obtained results (Salmond, 2008). Inter-rater reliability refers to the practice of engaging multiple researchers to evaluate the same questionnaire independently and, after that, compares their respective findings (Salmond, 2008). Using these methods, researchers can ensure that their questionnaire produces consistent results.

To ensure the validity of a questionnaire, researchers must ensure that it measures what it claims to measure (Higgins & Straub, 2006; Salmond, 2008). This can be achieved using established theory or findings from previous studies to develop the questionnaire (Higgins & Straub 2006). Researchers can also use statistical methods to measure validity, such as content validity, which involves ensuring that the questionnaire covers all relevant aspects of the studied topic (Sireci, 1998). The concept of construct validity pertains to the extent to which a questionnaire accurately measures the desired construct. In contrast, criterion validity is the process of comparing the answers obtained from the questionnaire to a pre-existing standard, as outlined by Sireci (1998).

In conclusion, questionnaires are a reliable and valid method of collecting data in quantitative research. Researchers can ensure that their results are accurate and meaningful by considering both reliability and validity when designing and administering questionnaires. To ensure reliability, researchers can use statistical methods to measure consistency, while to ensure validity, researchers must ensure that the questionnaire measures what it is supposed to measure.

3.10 Summary

This chapter provides an overview of the research methods, specifically focusing on the study design, setting, and sample techniques employed. The study included online surveys as a means of data gathering. The final section of this chapter encompasses an assessment of the reliability and validity of the presented information. The subsequent section provides an exposition of the findings.

Chapter 4

Data analysis and intepretation of the results

4. Introduction

This chapter presents the data obtained from the structured questionnaires administered to the following research respondents: architects, quantity surveyors, civil engineers, project managers and construction managers in the South African construction industry. The data analysis and interpretation of the results were obtained from the questionnaire study and served as the basis of this quantitative data collection. The questionnaire comprised forty-two questions, which were all answered.

4.1 Section A: biographical data analysis

This section presents background information of the respondents concerning their demographics, namely gender, age group, race, professional qualification, years of experience, highest qualification, employer type, location of the employer, and professional affiliation within the CBE.

4.1.1 Gender distribution sample

Table 4.1 presents the gender characteristics of the 42 respondents. There was male predominance (54.76 %) regarding the respondents in the study.

4.1.2 Age distribution sample

Most respondents were aged 21-30 (54.76%), followed by those aged 31-40 (26.19%) and 41-50 (19.05%), respectively. This is represented in Figure 4.1.

4.1.3 Qualifications distribution sample

The distribution of the sample according to professional qualification is demonstrated in Figure 4.1. It reveals that most respondents completed a postgraduate diploma (23.81%), followed closely by those who completed Baccalaureus Technologiae (21.43%), followed by those who completed a master's degree (16.67%) and Honors Degree (14.29%).

4.1.4 Current positions distribution sample

The distribution of the sample according to the respondents' current positions is presented in Figure 4.1. This shows that most respondents were in the middle level (52.38%) and senior level (29.19%).

4.1.5 Level of experience distribution sample

The distribution of the sample according to the respondents' years of experience in the construction industry is shown in Figure 4.1. It reveals that, most respondents had 11-15 (32.50 %), 6-10 (30.00 %) and 3-5 (25.00%) years of experience, respectively.

4.1.6 Size and location of the of organisation distribution sample

The distribution of the sample according to the respondents' organisational size and location are shown in Figure 4.1. Its shows that the size of the organisation of most respondents was large (47.62%) and small (30.95%), while organisations are in urban areas (64.29%) and in rural areas (35.71%).

4.1.7 Professional affiliation distribution sample

The distribution of the sample according to the respondents' professional affiliation is shown in Figure 4.1. It depicts that most respondents belonged to SACPCMP (48.72%) and ESCA (38.46%) professional councils.

Characteristic	n (%)	Missing (%)
Gender		
Male	23(54.76)	---
Female	19(45.24)	
Age Group		
21-30	23(54.76)	---
31-40	11(26.19)	
41-50	8(19.05)	
Level of Education		
National Diploma	5(11.90)	---
Postgraduate Diploma	10(23.81)	
Bachelor’s Degree	4(9.52)	
Baccalaureus Technologiea	9(21.43)	
Honours Degree	6(14.29)	
Master’s degree	7(16.67)	
Other	1(2.38)	
Job Position		
Unemployed	1(2.38)	---
Studying	1(2.38)	
Entry Level	1(2.38)	
Middle Level	22(52.38)	
Senior Level	11(29.19)	
Self Employed	1(2.38)	
Years of Experience		
Less than 1 Year	2(5.00)	2(5.00)
1-2 Years	1(2.50)	
3-5 Years	10(25.00)	
6-10 Years	12(30.00)	
11-15 Years	13(32.50	
16-20 Years	2(5.00)	
Size of Organisation		
Small (Less than 50 Employees)	13(30.95)	---
Medium (51-250 Employees)	9(21.43)	
Large (More than 250 Employees)	20(47.62)	
Location of Organisation		
Rural	4(9.52)	---
Urban	27(64.29)	
Suburban	11(26.19)	
Professional Council		
None	1(2.56)	3(7.14)
ASAQS and SAQS	1(2.56)	
ECSA	15(38.46)	
MRICS	1(2.56)	
SAICE	1(2.56)	
SACPCMP	19(48.72)	
SACSSP	1(2.56)	

Table 4. 1: Respondents characteristic

4.2 Section B: AI in construction industry

4.2.1 AI benefits in the construction industry

The adoption of AI in the construction industry has been gaining traction, with numerous benefits reported (Regona *et al*., 2022). Some key benefits include enhanced accuracy and quality, cost reduction, efficient resource use, and improved safety standards and practice, and these challenges require significant financial investment, upskilling and reskilling, sustainability, and sustainability. Figure 4.1 shows the perception of respondents on the benefits of adopting AI in the SA construction industry. Across all questions, most respondents thought that adopting AI in the SA construction industry is beneficial.

4.2.1.1 Accuracy and quality

AI can improve the accuracy and quality of construction outputs by automating processes and reducing human error (Abioye *et al*., 2021; Onososen & Musonda, 2022). The majority (67%) of respondents thought that AI adoption would help enhance the accuracy and quality of construction outputs.

4.2.1.2 Cost reduction

AI can help reduce overall costs in the construction industry by optimising resource allocation, streamlining processes, and improving efficiency (Onososen & Musonda, 2022; Mohapatra *et al.*, 2023). Similarly, most (69%) respondents perceived that AI adoption would be beneficial in reducing overall costs.

4.2.1.3 Efficient resource use

AI can lead to more efficient use of resources in the construction industry, such as materials, labour, and time (Adeloye *et al.*,2023). The majority (69%) of respondents believed that AI adoption will lead to more efficient use of resources in the construction industry, with the respondents giving “mostly always” as an answer, whereas 31% were more neutral.

4.2.1.4 Improved safety standards and practice

AI can improve safety standards and practices in the construction industry by monitoring and predicting accidents, as well as optimizing safety protocols (Onososen & Musonda, 2022). Regarding safety standards and practices in the SA construction industry, 64% of respondents perceived that AI adoption would be beneficial. However, there are some challenges and requirements associated with AI adoption in the construction industry.

4.2.1.5 Financial investment

Implementing AI in the construction industry requires a substantial financial investment in technology, infrastructure, and skilled personnel (Adeloye *et al.*, 2023). When asked if AI adoption requires significant financial investment for implementation in the SA construction industry, 83% of respondents answered always and often with equal proportions, with 14% responding sometimes.

4.2.1.6 Upskilling and reskilling

AI adoption may require the workforce to undergo upskilling and reskilling to adapt to new technologies and processes (Adeloye *et al.*, 2023). Regarding their perception of AI adoption requiring upskilling and reskilling, 79% of respondents thought often and always, with a higher proportion thinking always, whereas 19% thought sometimes.

4.2.1.7 Sustainability

AI can contribute to a more sustainable construction sector in SA by reducing waste, energy consumption, and greenhouse gas emissions (Onososen & Musonda, 2022).

Lastly, 62% of respondents thought AI adoption would benefit more sustainability in the SA construction industry. Interestingly, 33% of the respondents were more neutral in their perception of the benefit of AI adoption in sustainability in the SA construction industry.

In conclusion, AI has the potential to revolutionize the construction industry by offering numerous benefits, such as improved efficiency, safety, and sustainability. However, addressing the challenges and requirements associated with AI adoption is essential, including financial investment, workforce upskilling, and government support (Adeloye *et al.*, 2023).

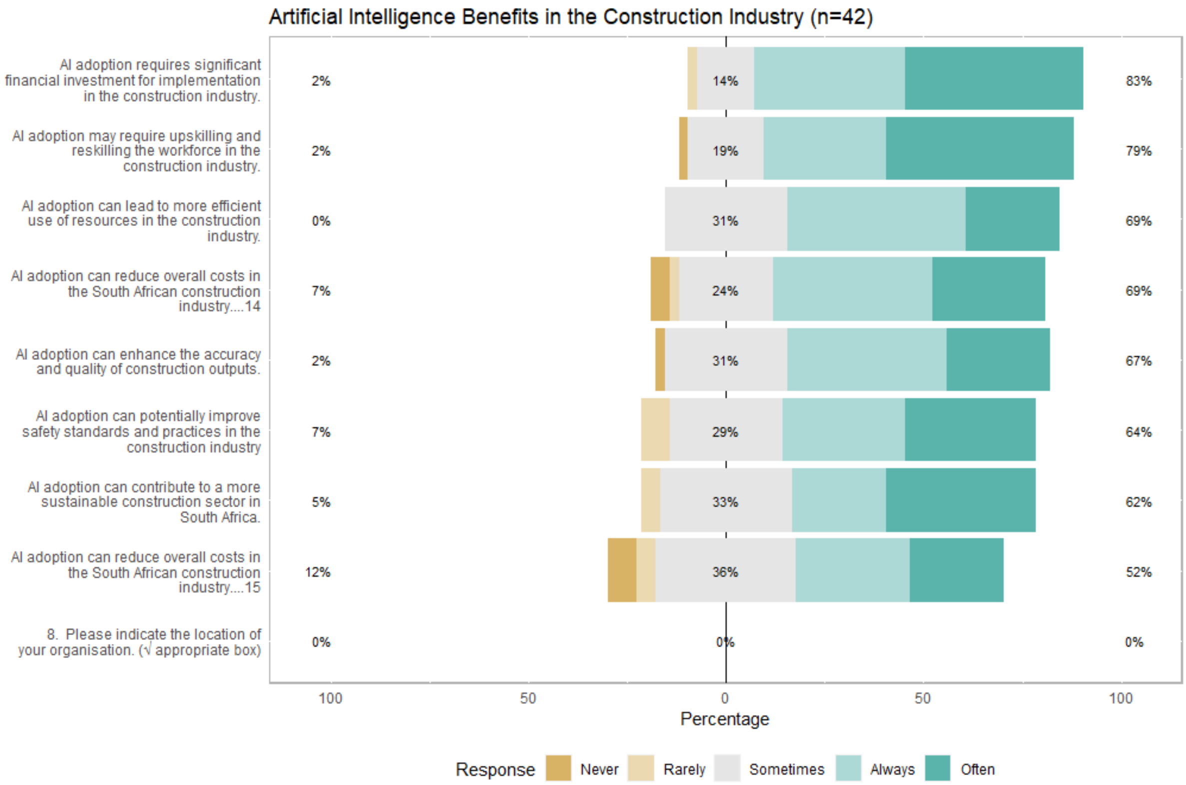

Figure 4. 1: Perception of 42 respondents on the benefits of AI adoption in SA construction industry

4.2.2 Impacts of artificial intelligence on productivity, costs, and employment in the South African construction industry

The adoption of AI in the South African construction industry has the potential to bring about significant changes (Olugboyega & Windapo, 2023). AI adoption in the South African construction industry can increase productivity. AI systems can automate repetitive tasks, optimise processes, and improve decision-making. AI can enhance overall productivity in construction projects by reducing manual labour and streamlining operations. This segment reviews, explores and analyses the impact of AI adoption on productivity, employment, and various aspects of the construction industry in SA. The identified impacts include improved work quality, cost savings, job loss, job creation, enhanced safety, better communication, improved visualisation, efficiency, improved project management, competitiveness, innovation, higher customer satisfaction, and improved environmental sustainability.

4.2.2.1 Quality of work

According to Chen *et al*. (2022), AI adoption in the South African construction industry can improve work quality through AI systems that can assist in design optimisation, error detection, and quality control. Lastly, through leveraging AI technologies, construction professionals can enhance the accuracy and precision of their work, resulting in improved work quality. In Figure 4.2 regarding their perception of AI adoption to improve work quality, 86% of the respondents demonstrate that AI adoption would enhance the quality of work, with the majority answering always.

4.2.2.2 Cost savings

Malomane, Musonda, and Okoro (2022) suggest that AI adoption in the South African construction industry can lead to cost savings as AI systems can optimise resource utilisation, reduce waste, and improve project scheduling by identifying inefficiencies and streamlining processes, construction companies can achieve cost savings in various aspects of their operations. Similarly, in Figure 4.2, when it came to their perceptions of AI adoption in SA construction leading to cost savings,76% of the respondents thought AI adoption would lead to cost savings.

4.2.2.3 Job loss and creation

Ejohwomu *et al.* (2021) believe that AI adoption in the South African construction industry may lead to job loss because automation of certain tasks through AI technologies can potentially replace human workers in specific roles. In Figure 4.2, Regarding AI adoption's impact on job losses, most (64%) respondents attest that AI adoption would increase jobs. However, it is important to note that AI adoption may also create new job opportunities that require different skill sets, thus mitigating the impact of job loss. Regarding the impact of AI adoption on creating new jobs, Figure 4.2 illustrates that 50% of respondents thought AI adoption would lead to creating new jobs, whereas 26% of respondents will not have a positive impact on creating new jobs.

4.2.2.4 Safety

AI adoption in the South African construction industry can improve safety since AI systems can assist in hazard detection, monitor construction sites, and improve safety protocols (Malomane *et al*., 2022). Safety can be achieved by using AI technologies by construction companies to enhance safety measures and reduce the risk of accidents and injuries. Regarding safety, Figure 4.2 points out that 64% of the respondents believed that AI adoption would improve safety in the SA construction industry.

4.2.2.5 Communication.

AI adoption in the South African construction industry can lead to better communication as AI systems can facilitate real-time data sharing, collaboration, and coordination among project stakeholders (Rahman & Gamil, 2019). Improved communication can enhance project efficiency, reduce delays, and improve project outcomes. Figure 4.2 supports the perceptions of AI adoption's impact on better communication, as 62% of the respondents thought AI adoption would lead to better communication.

4.2.2.6 Visualisation

AI adoption in the South African construction industry can improve visualisation (Onososen & Musonda, 2022). AI systems can assist in creating 3D models, virtual reality simulations, and augmented reality applications. These visualisation tools can enhance project planning, design, and communication among project teams and stakeholders. Figure 4.2 points out that 67% of the respondents thought it would have an increased impact on the SA construction visualisation.

4.2.2.7 Efficiency

AI adoption in the South African construction industry can increase efficiency (Onososen & Musonda, 2022). AI systems can automate repetitive tasks, optimise resource allocation, and improve project scheduling. AI technologies can enhance overall project efficiency by reducing manual labour and streamlining processes. Figures reveal that 81% of the respondents also believed that AI adoption in the SA construction industry would increase efficiency.

4.2.2.8 Project management

AI adoption in the South African construction industry can improve project management (Okoro *et al*., 2023). AI systems can assist in project planning, risk assessment, and decision-making. Zhu *et al*. (2022) believe that by leveraging AI technologies, project managers can enhance their ability to monitor progress, identify potential issues, and make informed decisions. Many respondents (81%) thought AI adoption in the SA construction industry would improve project management.

4.2.2.9 Competitiveness

AI adoption in the South African construction industry can increase competitiveness (Meno, 2020). By embracing AI technologies, construction companies can differentiate themselves in the market. AI can provide a competitive edge through improved efficiency, enhanced project outcomes, and the ability to offer innovative solutions. Regarding their perception of AI adoption in the SA construction industry increasing competitiveness, Figure 4.2 reflects that 76% of the respondents thought AI would increase competitiveness.

4.2.2.10 Innovation

AI adoption in the South African construction industry can lead to increased innovation (Lekan *et al.,* 2021). AI systems can assist in generating new design possibilities, optimising processes, and identifying novel solutions. By leveraging AI technologies, construction professionals can foster innovation and drive industry advancements. Figure 4.2 demonstrates when it came to the perception of AI adoption in the SA construction industry leading to innovation, 86% of the respondents thought AI adoption would lead to more innovation.

4.2.2.11 Customer satisfaction

AI adoption in the South African construction industry can increase customer satisfaction (Onososen & Musonda, 2022). AI systems can assist in project visualisation, design optimisation, and real-time client communication (Pan & Zhang, 2021). By leveraging AI technologies, construction companies can enhance customer engagement, meet client expectations, and deliver projects more efficiently. When they were asked about their view on the impact of AI on increasing customer satisfaction, Figure 4.2 illustrates that 69% thought AI adoption would lead to increased customer satisfaction.

4.2.2.12 Sustainability

AI adoption in the South African construction industry can improve environmental sustainability (Debrah *et al*., 2022). AI systems can optimise resource utilisation, reduce waste, and improve energy efficiency. By leveraging AI technologies, construction companies can adopt more sustainable practices, contributing to environmental preservation. Regarding their perceptions of the impact of AI adoption on environmental sustainability, in Figure 4.2, 67% of the respondents believed that AI adoption will lead to increased environmental sustainability.

The adoption of AI in the South African construction industry brings about various impacts, including increased productivity, improved work quality, cost savings, job loss, job creation, enhanced safety, better communication, improved visualisation, increased efficiency, improved project management, increased competitiveness, increased innovation, higher customer satisfaction, and improved environmental sustainability. While AI adoption may present challenges, it also offers opportunities for the construction industry to embrace technological advancements and drive positive change. Proper planning, stakeholder engagement, and skill development are necessary to maximise the benefits of AI adoption and mitigate potential risks.

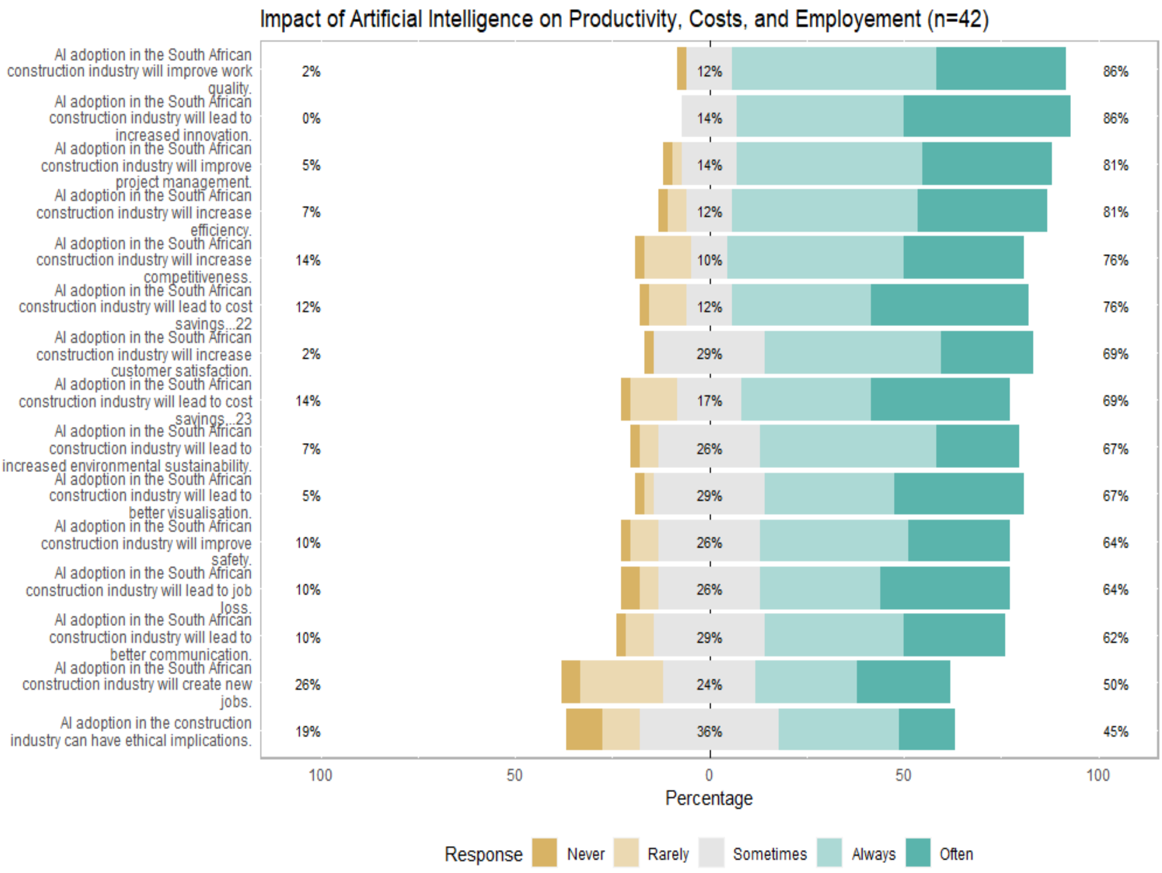

Figure 4. 2: Perception of 42 respondents on the impact of AI on productivity costs and employment.

4.2.3 The ethical and societal implications of AI adoption in the South African construction industry

Adopting Artificial Intelligence (AI) in the construction industry can revolutionise processes and improve efficiency (Pan and Zhang, 2021; Regona *et al*., 2022). However, it is essential to consider the ethical and societal implications of AI adoption. This section reviews and analyses the findings on the ethical and societal impacts of AI adoption in the construction industry. The identified implications include ethical concerns, societal impact, employment opportunities, quality of work, safety, environment, construction cost, speed of construction, construction accuracy, reliability, privacy of construction workers, construction site security, and trust between construction workers and AI systems.

4.2.3.1 Ethical implications

Adopting AI in the construction industry raises ethical concerns (Weber-Lewerenz, 2021; Sherratt, F., Dowsett, and Sherratt, S., 2020). The concerns include data privacy, algorithm bias, and transparency. AI systems rely on vast amounts of data, and ensuring the privacy and security of this data is crucial (Bharadiya, 2023). Additionally, algorithm bias can lead to unfair decision-making processes, impacting various stakeholders involved in construction projects (Metcalf *et al.,* 2021). The studies on ethical implications in Figure 4.3 show that 60% of the respondents always and often thought that AI adoption would impact the SA construction industry, with 36% being neutral.

4.2.3.2 Society

Adopting AI in the construction industry can significantly impact society (Cubric, 2020). AI can disrupt traditional job roles and employment opportunities (Sherratt, F., Dowsett, and Sherratt, S., 2020). While AI can automate specific tasks, it may also create new job opportunities that require different skill sets (Frank *et al*., 2019). Balancing the societal impact of AI adoption is crucial to ensure a fair and inclusive transition; this is evident in Figure 4.3, that AI adoption impacts society by 55% of the respondents who always and often thought that AI would impact society, whereas 33% were neutral.

4.2.3.3 Employment

Newman *et al.* (2022) demonstrate that AI adoption in the construction industry can impact employment opportunities; while AI can also automate repetitive and mundane tasks, it may result in job displacement for workers engaged in those tasks (Tschang, and Almirall, 2021). However, AI can also create new job roles that require higher-level skills, such as managing and maintaining AI systems. Proper planning and reskilling initiatives are necessary to mitigate the potential negative impacts on employment. The studies are alluded to in Figure 4.3, by 67% always and often thought that AI adoption would impact employment opportunities in the SA construction industry.

4.2.3.4 Quality of work

Pan and Zhang, (2021) found that AI adoption in the construction industry can impact the quality of work. AI systems can assist in detecting errors, optimising designs, and improving construction processes (Baduge *et al*., 2022). However, Regona *et al*. (2022) state that the reliance on AI systems may also introduce new risks and challenges that must be carefully managed to ensure the quality and integrity of construction projects. In Figure 4.3, 67% of respondents agree with the literature that always and often thought that AI adoption would positively impact the quality of work in the SA construction industry.

4.2.3.5 Safety

AI adoption in construction can have safety implications (Regona *et al*., 2022). AI systems can help identify potential hazards, monitor construction sites, and improve safety protocols (Okpala, Nnaji, and Karakhan, 2020). However, the reliance on AI systems also introduces new risks, such as system failures or errors in decision-making (Shrestha, Ben-Menahem, and Von Krogh, 2019). Ensuring the safety of workers and implementing appropriate safeguards is critical when adopting AI in construction; this is proven in Figure 4.3 by 52% of the respondents who always and often thought AI adoption would impact safety, with 31% being neutral.

4.2.3.6 Environmental

AI adoption in the construction industry can have positive and negative environmental impacts (Zhang *et al.,* 2022). AI systems can optimise resource utilisation, reduce waste, and improve energy efficiency in construction processes (Abioye *et al*., 2021). However, according to Oláh *et al.* (2020), the production and disposal of AI technologies may have environmental consequences. Balancing the environmental impact of AI adoption is necessary to ensure sustainable construction practices; this is substantiated by 52% of the respondents in Figure 4.3, who indicated that AI adoption often has an environmental impact.

4.2.3.7 Construction costs

AI adoption in the construction industry can impact construction costs (Akinosho *et al.,* 2020). While AI systems can optimise processes and reduce inefficiencies, AI technologies' initial investment and maintenance costs may be significant (Abioye *et al*., 2021). Proper cost-benefit analysis and long-term planning are essential to accurately evaluate the financial implications of AI adoption. In Figure 4.3, regarding the AI impact on construction costs, 64% of the respondents concur with previous studies that always and often perceived that AI adoption will have a positive impact.

4.2.3.8 Speed of construction

AI adoption in the construction industry can impact the speed of construction projects (Akinosho *et al*., 2020). AI systems can help streamline processes, automate tasks, and improve project scheduling (Pan and Zhang, 2021). However, the integration and learning curve associated with AI implementation may initially slow down construction processes. Proper planning and training are necessary to maximise the benefits of AI adoption and minimise any temporary delays. Similarly, in Figure 4.3, 71% of the respondents approve that they always and often perceived that AI adoption in the SA construction industry will impact the speed of construction.

4.2.3.9 Construction accuracy

AI adoption in the construction industry can impact the accuracy of construction projects (Wang *et al*., 2020). AI systems can assist in design optimisation, error detection, and quality control (Baduge *et al.*, 2022). Nevertheless, the accuracy of AI systems heavily relies on the quality and reliability of input data. Ensuring data accuracy and implementing appropriate validation processes are crucial to maintaining construction accuracy. Correspondently, in Figure 4.3, 62% of the respondents always and often thought that AI adoption would positively impact construction accuracy.

4.2.3.10 Reliability

AI adoption in the construction industry can impact the reliability of construction projects (Abioye *et al*., 2021; Wang *et al*., 2020). AI systems can assist in predicting risks, optimising processes, and enhancing decision-making (Rafsanjani and Nabizadeh, 2023). However, the reliability of AI systems depends on the quality of algorithms, data, and system performance. Regular maintenance, testing, and validation are necessary to ensure the reliability of AI systems in construction. Regarding AI adoption in the SA construction industry's impact on the reliability of construction, in Figure 4.3, 71% of respondents agree that always and often thought that AI will have implications, the majority responding always.

4.2.3.11 Privacy

Wang *et al*. (2020) state that AI adoption in the construction industry can impact the privacy of construction workers since AI systems may collect and analyse personal data, such as biometrics or location information, to improve safety or monitor productivity. Safeguarding the privacy and consent of construction workers is crucial to address potential privacy concerns and maintain trust. Figure 4.3 shows the perception of the respondents on the impact of AI adoption on the privacy of construction workers, with almost equal proportions: 43% always and often thought AI would impact, and 40% were neutral.

4.2.3.12 Security

Pan and Zhang (2021) note AI adoption in the construction industry can impact construction site security through AI systems that can assist in monitoring and detecting security threats, such as unauthorised access or theft. However, the reliance on AI systems also introduces new vulnerabilities, such as cyber-attacks or system breaches. Implementing robust security measures and regular updates are necessary to ensure construction site security. Figure 4.3 demonstrates a contrast in the respondents' perception of AI's impact on on-site safety; 43% were neutral, and 40% always and often thought AI would have a positive impact.

4.2.3.13 Trust

Wang *et al*. (2020) also indicate that AI adoption in the construction industry can impact the trust between construction workers and AI systems through the successful integration of AI that requires the acceptance and trust of the workforce. Ensuring transparency, providing proper training, and involving workers in decision-making processes can foster trust and facilitate the adoption of AI technologies. Regarding their perceptions of the impact of AI adoption on the trust between construction workers and AI systems, 50 % of the respondents were always positive, with 40% being neutral.

4.2.3.14 Ethical and societal

Adopting AI in the construction industry brings numerous ethical and societal implications that must be carefully considered. Addressing these implications requires a balanced approach prioritising privacy, fairness, safety, and sustainability. Proper planning, stakeholder engagement, and regulatory frameworks are necessary to ensure AI's responsible and beneficial integration in the construction industry.

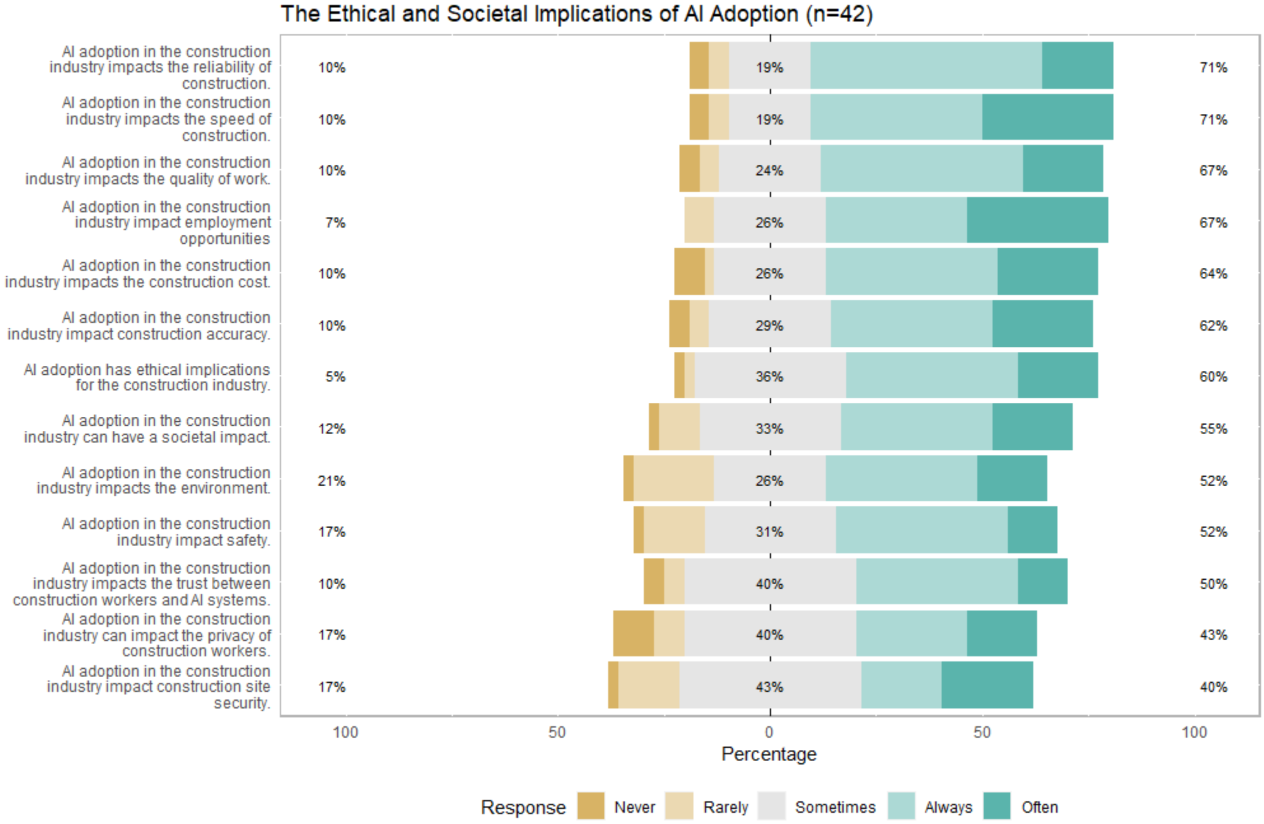

Figure 4. 3: Perceptions of 42 respondents on the impact of AI adoption on ethical and societal implications

4.2.4 Barriers to the adoption of ai in civil engineering projects in South Africa

Artificial Intelligence (AI) can potentially revolutionise civil engineering by improving efficiency, accuracy, and decision-making processes (Pan, and Zhang, 2021; Manzoor *et al*., 2021). However, the adoption of AI in civil engineering projects could be improved by overcoming barriers. The literature review aims to explore and analyse the barriers to AI adoption in civil engineering, focusing on SA.

4.2.4.1 Awareness

One of the primary barriers to AI adoption in civil engineering projects in SA is a need for more awareness (Olanrewaju *et al.,* 2022; Ayodele and Kajimo-Shakantu, 2022). Many professionals in the field of Architecture, Engineering and Construction (AEC) need to be adequately informed about AI's potential benefits and applications (Darko *et al.,* 2022). The lack of awareness hinders the integration of AI technologies into existing practices and limits the exploration of innovative solutions, and in Figure 4.4, 70% of the respondents agree that there needs to be more awareness of AI technology in SA civil engineering projects.

4.2.4.2 Technical expertise

According to Pan and Zhang (2021), implementing AI in civil engineering projects requires specialised technical expertise. However, there is a significant need for more professionals with the necessary skills and knowledge to develop and deploy AI solutions (Maity, 2019). Hwang, Ngo, and Teo (2022) also state that a lack of technical expertise poses a major barrier to the successful adoption and integration of AI technologies in the civil engineering sector. The literature is supported by Figure 4.4, whereby 79% of the respondents' perceptions of lack of technical expertise to implement AI in civil engineering projects in SA always and often thought there were shortcomings.

4.2.4.3 Lack of funding

Darko *et al.* (2022) argue that implementing AI in civil engineering projects often requires significant financial resources. However, according to Mbunge *et al.* (2022), there needs to be more funding explicitly allocated for AI implementation in SA. Limited financial support restricts the ability of civil engineering organisations to invest in AI technologies, hindering progress and innovation in the field. Figure 4.4 supports the study by Mbunge *et al.* (2022). Regarding the lack of funding for AI implementation in civil engineering projects in SA, 83% of the respondents always and often thought there was a lack of funding for such undertakings.

4.2.4.4 SA government

Hwang, Ngo, and Teo (2022) say that government support plays a crucial role in facilitating the adoption of AI in civil engineering projects. However, the study by Aguera *et al*. (2020) found that SA lacks comprehensive policies and initiatives that promote and incentivise the integration of AI technologies. The absence of government support hampers the widespread adoption of AI in the civil engineering sector. This is reflected in Figure 4.4, regarding the lack of government support in civil engineering projects in SA; 83% of the respondents always and often thought that the SA government is not giving sufficient support in AI adoption in civil engineering projects in SA, with the most perception being often.

4.2.4.5 Lack of trust

Trust is critical in adopting any new technology, including AI (Kim, Giroux, and Lee, 2021). In SA, there is a lack of trust in AI technology within the civil engineering community (Olojede, Agbola, and Samuel, 2019). Concerns regarding AI's reliability, accuracy, and potential job displacement hinder its acceptance and implementation. Building trust in AI technology requires transparent communication, education, and demonstration of its benefits. The literature regarding the respondents' perceptions of the lack of trust in AI technology in civil engineering projects in SA is supported by 70% of respondents, who thought there is often a lack of trust in AI technology.

4.2.4.6 Cultural barriers

Cultural factors can also act as barriers to the adoption of AI in civil engineering projects in South Africa (Lubinga, Maramura, and Masiya, 2023). The resistance to change and the preference for traditional methods may hinder the acceptance and integration of AI technologies (Wang *et al.,* 2022). Cultural barriers need to be addressed through awareness campaigns, education, and showcasing successful AI implementations to overcome resistance and promote acceptance. In Figure 4.4, 55%

of respondents always and often thought there were cultural barriers to using AI technologies in SA civil engineering projects.

The barriers to AI adoption in civil engineering projects in SA are multifaceted and interconnected. Addressing these barriers requires a comprehensive approach that includes raising awareness, developing technical expertise, securing funding, fostering government support, building trust in AI technology, and addressing cultural barriers. Overcoming these barriers is crucial to unlock the full potential of AI in civil engineering, leading to improved project outcomes, increased efficiency, and sustainable development.

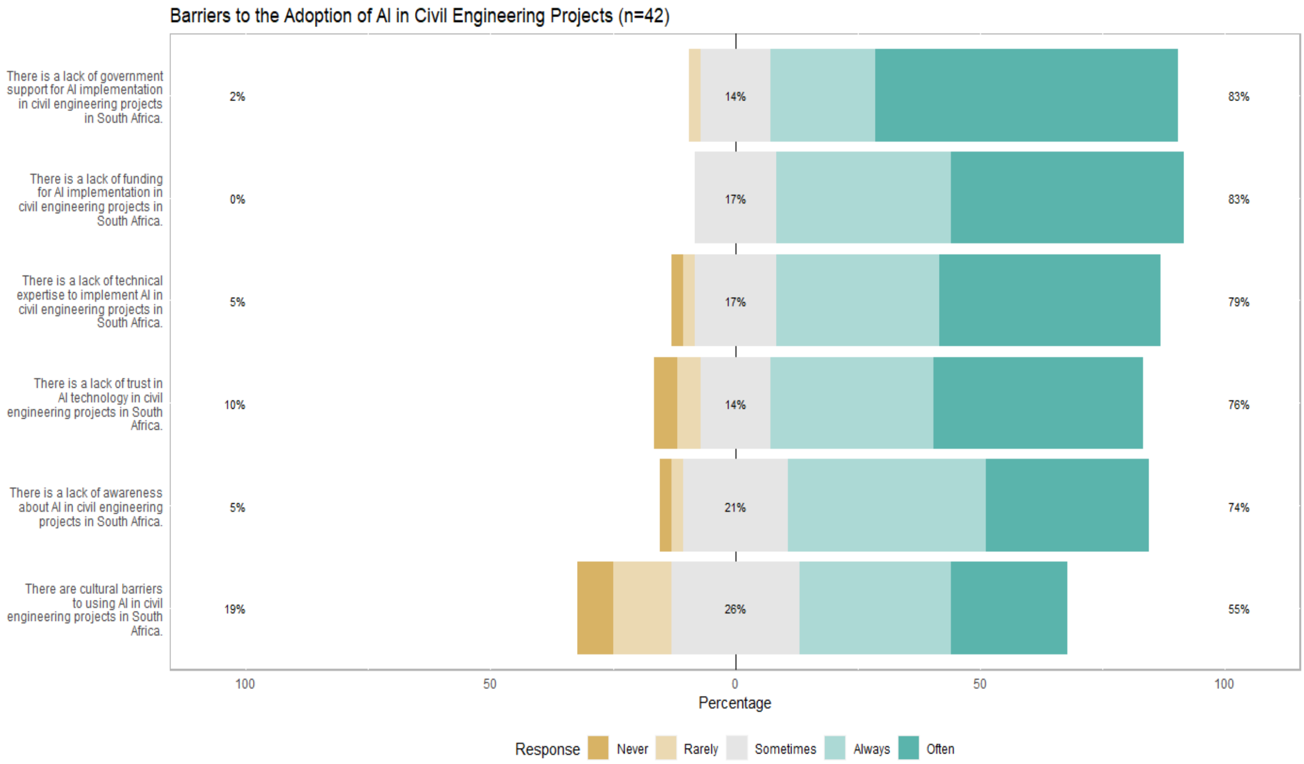

Figure 4. 4: Perception to barriers to the adoption of ai in civil engineering projects in South Africa

4.3 Summary

These results highlighted that most patients were male (54.76%), aged 21-30 (54.76%), and had post-graduate qualifications. The results also highlighted that most respondents thought adopting AI in the SA construction would be beneficial. Furthermore, AI would improve work quality and lead to more innovations in the SA construction industry. Moreover, most respondents thought that AI would improve reliability and the speed of construction, respectively.

Chapter 5

Summary, Conclusions, Discussion, and Recommendations

5. Introduction

This chapter discusses the findings from the research analysis concerning the research questions. The reviewed literature in Chapters 2 and 4 further discusses the results. This is to ascertain whether the defined research questions have been answered from the data analysis in Chapter Four. Results are presented concerning the research question and the relevant data as required.

The following research questions were used to guide the study on an assessment of adoption AI in the South African construction industry:

- What are the potential economic benefits and drawbacks of AI adoption in the South African construction industry?
- How will the AI adoption impact productivity, costs, and employment in the South African construction industry?
- What are the ethical and societal implications of AI adoption in the South African construction industry?
- How can these barriers be addressed to adopt of AI in Civil engineering projects in South Africa?

5.1 Research question 1 (RQ1)

What are the potential economic benefits and drawbacks of AI adoption in the South African construction industry?

5.1.1 Findings

The study's first aim was to assess respondents' perceptions of the benefits of AI adoption in the SA construction industry. Like previous studies, most (83%) respondents thought AI adoption in the SA construction industry would require a significant financial investment. Moreover, most respondents thought AI adoption in the SA construction industry would be beneficial in the skilling and reskilling of employees (79%), efficient use of resources (69%), reduction of overall costs (69%), and enhancement of accuracy and quality of construction outputs (64%).

5.1.2 Discussion

According to the study, most respondents (83%) thought that adopting AI in the South African construction industry would require a significant financial investment. However, they also believed that AI adoption would be beneficial in the skilling and reskilling of employees (79%), efficient use of resources (69%), reduction of overall costs (69%), and enhancement of accuracy and quality of construction outputs (64%). The study also notes that the adoption of AI techniques has helped to enhance automation and provide better competitive advantages as compared to conventional approaches (Abioye *et al.*, 2021).

Furthermore, the adoption AI enhances productivity and reduce the high incidence of waste generated on-site, achieving better quality in construction project delivery, improving construction workflow and productivity, and achieving sustainable cost in the long term (Onososen & Musonda, 2022). Therefore, the study suggests that policymakers and construction firms should consider the benefits of AI adoption in the construction industry to improve organisational competitiveness and achieve an industrialised construction operation (Onososen & Musonda, 2022; Abioye *et al.*, 2021).

5.1.3 Implications of the results

The implications of the study's findings are significant for the field of research and practice. They provide insights into how adopting Artificial Intelligence (AI) in the South African construction industry could impact various aspects. The implications include the need for a significant financial investment, the potential for skilling and reskilling of employees, efficient use of resources, reduction of overall costs, and enhancement of accuracy and quality of construction outputs. These implications can guide future research, inform policymaking, and influence industry practices. It is essential to consider the practical and theoretical implications of the findings and their potential impact on policies, theories, and practices within the construction industry. Additionally, the implications should be evidence-based and derived from the study's results, providing a basis for further exploration and decision-making.

5.1.4 Recommendations

Based on the study's findings, the following recommendations can be made for the South African construction industry: 1. Investment in AI: Despite the perceived need for a significant financial investment, stakeholders in the SA construction industry should consider the long-term benefits of AI adoption, such as improved efficiency, reduced costs, and enhanced quality of construction outputs. 2. Employee Training: Given the potential for skilling and reskilling employees through AI adoption, construction firms should invest in training programs to equip their workforce with the necessary skills to effectively leverage AI technologies. 3. Resource Management: Emphasize the efficient use of resources by integrating AI technologies to optimize resource allocation, minimize waste, and improve sustainability in construction projects. 4. Quality and Accuracy: Focus on leveraging AI to enhance the accuracy and quality of construction outputs, thereby improving overall project outcomes and client satisfaction. 5. Policy Considerations: Policymakers should explore ways to incentivize AI adoption in the construction industry, potentially through subsidies, tax incentives, or regulatory frameworks that promote the responsible integration of AI technologies. These recommendations are based on the study's findings and aim to guide industry stakeholders, policymakers, and researchers in leveraging AI to advance the SA construction sector.

5.1.5 Conclusion

In conclusion, the study's findings underscore the perceived benefits and challenges associated with adopting AI in the South African construction industry. Most respondents recognised the need for a significant financial investment in AI adoption, acknowledging the potential for skilling and reskilling employees, efficient resource utilisation, cost reduction, and improved construction output quality. These insights highlight the importance of carefully considering the implications of AI integration in the construction sector. Moving forward, industry stakeholders and policymakers must address the financial considerations while leveraging AI to enhance workforce capabilities, resource management, and overall project outcomes. Furthermore, the study's findings emphasise the need for strategic planning and investment in AI to drive innovation and competitiveness within the SA construction industry. Overall, the study provides valuable insights that can inform future research, policy development, and industry practices in the context of AI adoption in construction.

5.2 Research question 2 (RQ2)

"*How will the AI adoption impact productivity, costs, and employment in the South African construction industry?"*

5.2.1 Findings

The study's second aim was to explore respondents' perspectives on the impacts of AI on productivity, costs, and employment in the South African construction industry. Most respondents believed that AI benefits productivity, costs, and employment. The majority (86%) of respondents thought AI would improve the quality of work and lead to more innovations in the SA construction industry, as in other studies. In the literature, it has been reported that AI improves project management and efficiency; in this study, the trend was the same, at 81%. Previous reports have shown that managers in the construction industry thought that AI adoption would benefit the industry's sustainability; in this study, the findings were similar (62%). However, some respondents were more neutral (33%).

5.2.2 Discussion

The study's findings indicate that most South African construction industry respondents believe that adopting Artificial Intelligence (AI) would benefit productivity, costs, and employment, aligning with existing literature. Specifically, 86% of respondents anticipate improved work quality and innovation, while 81% expect enhanced project management and efficiency. Moreover, 62% of respondents believe that AI adoption would benefit the industry's sustainability, although 33% remain neutral. These findings are consistent with existing research, such as the impact of productivity and investment on employment absorption rate in SA (Habanabakize *et al.*, 2019), the effect of government expenditure and revenues on labour productivity (Phiri & Mbaleki, 2022), and the need to improve productivity and public spending efficiency in SA. The study's results contribute to the understanding of AI's potential impact on the construction industry in SA, aligning with broader discussions on productivity, investment, and real wages in the country (Habanabakize *et al.*, 2019).

5.2.3 Implication of the results

The implications of the study's results suggest several avenues for further research and practical applications. Firstly, the overwhelmingly positive perception of AI among respondents in the South African construction industry indicates a potential shift towards AI adoption, which could lead to improved productivity, cost-effectiveness, and employment opportunities. This warrants further investigation into how AI implementation can enhance work quality, innovation, and project management efficiency. Additionally, the study's finding that a significant proportion of respondents were neutral about the potential benefits of AI adoption for industry sustainability highlights the need for research to delve into the factors influencing this neutrality and to explore strategies for addressing any reservations. Furthermore, the study's alignment with existing literature on the impact of productivity and investment on employment absorption rate in SA underscores the relevance of AI adoption in the context of broader discussions on productivity and employment in the country, suggesting the need for interdisciplinary research to understand the potential macroeconomic implications of widespread AI integration in the construction industry (Habanabakize *et al.*, 2019).

5.2.4 Recommendations

Based on the study's results, several recommendations can be made for future research: Further research is needed to understand how AI implementation can enhance work quality, innovation, and project management efficiency in the South African construction industry. Research is needed to explore the factors influencing the neutrality of some respondents towards the potential benefits of AI adoption for industry sustainability. Interdisciplinary research is needed to understand the potential macroeconomic implications of widespread AI integration in the construction industry in SA. Future research could explore the potential barriers to AI adoption in the construction industry and strategies for addressing them. These recommendations can help guide future research and inform policy decisions related to AI adoption in the South African construction industry.

5.2.5 Conclusion

The study's conclusion reveals the overwhelmingly positive perception of AI among respondents in the South African construction industry, indicating a potential shift towards AI adoption and its potential benefits for productivity, cost-effectiveness, and employment opportunities. The findings align with existing literature on the impact of productivity and investment on the employment absorption rate in SA, highlighting the relevance of AI adoption in broader discussions on productivity and employment in the country. Furthermore, the study's results suggest the need for further research to understand the mechanisms through which AI implementation can enhance work quality, innovation, and project management efficiency, as well as to explore strategies for addressing any reservations about the potential benefits of AI adoption for industry sustainability. These implications underscore the significance of AI in the construction industry and its potential macroeconomic implications, warranting interdisciplinary research to understand its broader impact.

5.3 Research question 3 (RQ3)

“What are the ethical and societal implications of AI adoption in the South African construction industry?”

5.3.1 Findings

The third aim of the study was to evaluate respondents' views on the ethical and societal Implications of AI Adoption in the South African construction industry. Like previous studies, respondents thought AI in SA construction would have societal and ethical implications in most questions. Most respondents (71%) believed that AI would positively impact the reliability and speed of construction, respectively. The positive sentiment extends to perceptions about the impact of AI adoption on the quality of work (67%) and employment opportunities (67%) in the SA construction industry. This suggests a belief that AI technologies can improve both the sector's output quality and employment prospects. Respondents expressed a range of opinions on the ethical implications of AI adoption in the SA construction industry, with 60% believing it would have an impact. This indicates concern and awareness regarding the ethical considerations associated with AI integration.

5.3.2 Discussion

The findings suggest that respondents in the South African construction industry believe that adopting AI would have ethical and societal implications. Most respondents expressed positive views on the impact of AI adoption, with 71% believing it would positively affect the reliability and speed of construction and 67% expressing optimism about its impact on the quality of work and employment opportunities. However, 60% of respondents also expressed concern about the ethical implications of AI adoption in the industry, indicating awareness of the associated ethical considerations. The findings align with existing research on ethical concerns in the construction industry, including bribery, collusion, fraud, negligence, and unfair practices (Bowen *et al.*, 2007; Amoah & Steyn, 2022). The study also highlights the importance of organisational factors in driving the adoption of AI in construction organisations, emphasising the need for technology infrastructure, human resources expertise, and organisational commitment to change (Tjebane *et al.*, 2022). Additionally, it points out the challenges and issues that may impede the adoption of AI practices in construction supply chains, which can have implications for construction organisations' ethical and governance fabric (Singh *et al.*, 2023).

5.3.3 Implication of the results

The implications of the findings in the study on the ethical and societal implications of AI adoption in the South African construction industry are significant. Implications in research refer to the impact of the findings on the field of study and potential questions that justify further exploration. They discuss how the research findings could affect policies, theories, and practices and can be practical or theoretical. In this context, the positive views on the impact of AI adoption on reliability, speed, quality of work, and employment opportunities in the construction industry suggest potential practical implications for improving the sector's output quality and employment prospects. Additionally, the concerns expressed by respondents about the ethical implications of AI adoption indicate the need for further exploration and consideration of ethical frameworks in the industry. These implications are important for policymakers, practitioners, and future research in the field, as they provide insights into the potential impact of AI adoption on the construction industry in SA.

5.3.4 Recommendations

The recommendations based on the study's findings on the ethical and societal implications of AI adoption in the South African construction industry should focus on specific actions that can be taken to address the implications identified. These recommendations should be evidence-based and derived from the results of the study. They can be theoretical and practical, addressing social, political, or other relevant aspects. Given the positive views on the impact of AI adoption on reliability, speed, quality of work, and employment opportunities, recommendations could include: 1. Developing guidelines for the ethical integration of AI technologies in the construction industry to address the concerns expressed by respondents. 2. Investing in training and upskilling programs to prepare the workforce for integrating AI technologies, ensuring that the potential benefits for employment opportunities are realised. 3. Establishing mechanisms for monitoring and evaluating the impact of AI adoption on the quality of work and construction processes to ensure continuous improvement. Based on the study's findings, these recommendations aim to improve the field and contribute to ongoing theory, practice, and policymaking in the South African construction industry (Regona *et al.*, 2022).

5.3.5 Conclusion

The conclusion drawn from the findings of the study on the ethical and societal implications of AI adoption in the South African construction industry is that while there is optimism about the positive impact of AI adoption on reliability, speed, quality of work, and employment opportunities, there are also concerns about the ethical implications. These findings have significant implications for the construction industry in SA and warrant further exploration and consideration. The study's implications highlight the potential impact of AI adoption on policies, theories, and practices in the construction industry. They also underscore the need for ethical frameworks to guide the integration of AI technologies. The practical and theoretical implications of the findings provide valuable insights for policymakers, practitioners, and future research in the field. In conclusion, the study's findings call for developing guidelines for ethical AI integration, investment in workforce training, and mechanisms for monitoring the impact of AI adoption on construction processes. These recommendations aim to address the implications identified and contribute to advancing theory, practice, and policymaking in the South African construction industry (Kiemde & Kora, 2021).

5.4 Research question 4 (RQ 4)

“How can these barriers be addressed to adopt of AI in Civil engineering projects in South Africa?”

5.4.1 Findings

The fourth aim of this study is to assess the barriers to adopting AI in civil engineering projects in SA. A significant majority (83%) of respondents consistently believed that the South African government needs to provide more support for adopting AI in civil engineering projects. This perception suggests a critical need for increased government involvement and policies that promote and facilitate the integration of AI technologies in the civil engineering sector. Similarly, 83% of respondents believed there needs to be more funding for AI implementation in civil engineering projects in SA. Limited financial resources can impede the development and deployment of AI solutions, emphasising the importance of addressing funding challenges to accelerate technological advancements. A significant portion (79%) of respondents consistently perceived the need for more technical expertise as a barrier to implementing AI in civil engineering projects. This underscores the need for training programs and initiatives to enhance the technical skills of professionals in the industry, ensuring they are well-equipped to leverage AI technologies effectively. 70% cent of respondents expressed concerns about the need for more trust in AI technology in civil engineering projects.

Building trust is crucial for successfully adopting AI, and addressing these concerns may involve initiatives to improve transparency, reliability, and understanding of AI systems in the civil engineering context.

Moreover, the results revealed that 70% of respondents believe there needs to be more awareness about AI technology in South African civil engineering projects. This highlights the importance of educational efforts and awareness campaigns to inform professionals in the industry about the potential benefits and applications of AI. Approximately 55% of respondents believed cultural barriers exist in using AI technologies in South African civil engineering projects. Cultural factors can influence the acceptance and adoption of new technologies, emphasising the need for culturally sensitive approaches and strategies to foster a positive attitude towards AI.

5.4.2 Discussion

The findings suggest a varied perspective on the environmental consequences of AI adoption in construction, with 52% of respondents believing it would have a positive impact. Similarly, while 52% of respondents believed AI adoption would impact safety positively, 31% were neutral. Respondents exhibited positive perceptions regarding the impact of AI adoption on the trust between construction workers and AI systems. However, opinions were more divided on the impact of AI on the privacy of construction workers and on-site safety. These variations highlight the nuanced and multifaceted nature of attitudes toward specific AI-related concerns. The study also identified several barriers to adopting AI in civil engineering projects in SA. A significant majority of respondents believed that the South African government needs to provide more support for adopting AI in civil engineering projects, and there needs to be more funding for AI implementation. Respondents also perceived the need for more technical expertise as a barrier to implementing AI in civil engineering projects.

Additionally, respondents expressed concerns about the need for more trust in AI technology in civil engineering projects and more awareness about AI technology in

South African civil engineering projects. Cultural barriers were also identified as a concern, highlighting the need for culturally sensitive approaches and strategies to foster a positive attitude towards AI. The findings suggest that addressing concerns related to ethics, trust, data security, workforce impact, and regulatory challenges is crucial for building trust and promoting the adoption of AI in construction. Prioritising ethical considerations, building trust through transparency and education, ensuring data quality and security, addressing workforce impact through reskilling, and collaborating with policymakers to establish clear regulatory frameworks can help overcome these concerns. Additionally, educational efforts and awareness campaigns can inform professionals in the industry about the potential benefits and applications of AI.

5.4.3 Implication of the results

The implications of the findings from the study on AI adoption in construction and civil engineering projects in SA are significant for policy, practice, theory, and subsequent research. The findings suggest a need for increased government support and funding for AI implementation in civil engineering projects. The findings imply a critical need for policies that promote and facilitate the integration of AI technologies in the civil engineering sector. Additionally, the study highlights the importance of addressing funding challenges to accelerate technological advancements and the need for training programs to enhance the technical skills of professionals in the industry.

Moreover, the findings emphasize the importance of building trust in AI technology and the need for more awareness about AI technology in South African civil engineering projects. Cultural barriers were also identified as a concern, highlighting the need for culturally sensitive approaches and strategies to foster a positive attitude towards AI. These implications provide valuable insights for policymakers, industry professionals, and researchers, guiding future actions and decision-making to promote the responsible and effective adoption of AI in construction and civil engineering projects in SA.

5.4.4 Recommendations

Based on the findings, the following recommendations can be made to address the implications of AI adoption in construction and civil engineering projects in SA: 1. Government Support and Funding: The South African government should provide more support and funding for AI implementation in civil engineering projects. It can be achieved by developing policies that promote and facilitate the integration of AI technologies in the civil engineering sector. 2. Technical Expertise and Training: Initiatives should be implemented to enhance the technical skills of professionals in the industry. Training programs and initiatives can ensure that professionals are well-equipped to leverage AI technologies effectively. 3. Building Trust and Awareness: Efforts should be made to build trust in AI technology and increase awareness about AI technology in South African civil engineering projects. This can be achieved through transparency, reliability, educational efforts, and awareness campaigns to inform professionals in the industry about the potential benefits and applications of AI. 4. Addressing Cultural Barriers: Culturally sensitive approaches and strategies should be developed to foster a positive attitude towards AI. Understanding and addressing cultural factors that influence the acceptance and adoption of new technologies is crucial for successful AI implementation in the construction and civil engineering. These recommendations align with the study's implications. They can guide policymakers, industry professionals, and researchers in promoting the responsible and effective adoption of AI in construction and civil engineering projects in SA.

5.4.5 Conclusion

In conclusion, the study's implications on AI adoption in construction and civil engineering projects in SA suggest a need for increased government support and funding for AI implementation, technical expertise, and training, building trust and awareness, and addressing cultural barriers. These implications provide valuable insights for policymakers, industry professionals, and researchers, guiding future actions and decision-making to promote the responsible and effective adoption of AI in construction and civil engineering projects in SA. The study also highlights the importance of implications in research, which explains the significance of research findings and how they may impact policies, theories, and practices. Implications should be evidence-based and substantiated by the study's parameters and results, and potential limitations of the methodology or sample should be considered to avoid over generalisation. Future research can build on these implications to further explore the potential benefits and challenges of AI adoption in construction and civil engineering projects in SA.

5.5 Strengths and Limitations

Strengths of the study include that cross-sectional surveys are relatively quick and cost-effective. They allow researchers to collect data from a large sample of participants simultaneously, making them efficient for exploring various variables and research questions. Furthermore, cross-sectional surveys provide a snapshot of the population at a specific moment, making them suitable for describing the prevalence of conditions, behaviours, or attitudes.

One of the most significant limitations of cross-sectional surveys is that causality could be established in the study. Another limitation is that the nonresponse and participation bias affected the sample's representativeness, potentially skewing the results. Respondents who chose to participate in the survey may differ from those who did not, which might have led to selection bias. Although the study's sample size was sufficient, a larger sample would have made the results more generalisable.

5.6 Future studies recommendations

Recommendations for future studies on AI adoption in the South African construction industry future studies on the adoption of AI in the South African construction industry could focus on several critical areas based on the existing research: 1. Empirical

Studies: Conduct empirical studies to understand the current situation of AI adoption factors in South African construction organizations (Tjebane *et al.*, 2022). 2. Organizational Factors: Investigate the factors influencing AI adoption, such as performance, cost, government pressure, and knowledge (Tjebane *et al.*, 2022). 3. Quantitative Surveys: Utilise quantitative surveys to identify organisational factors imperative to driving the adoption of AI in construction organizations (Tjebane *et al.*, 2022). 4. Impact on Efficiency and Productivity: Explore the impact of AI technologies on efficiency, productivity, and job roles within the construction sector. 5. Collaboration and Trust: Investigate how factors like mutuality, trust, institutional support, project context, and shared purpose contribute to collaboration in the adoption of AI in the construction industry (Tjebane *et al.*, 2022). 6. Smart Technologies: Study the investment trends and the adoption of new intelligent technologies, including AI, in the construction sector. By addressing these areas, future studies can contribute to a clearer understanding of the organizational factors and the impact of AI adoption in the South African construction industry, providing valuable insights for industry stakeholders and policymakers.

5.7 Conclusion

In conclusion, the survey results underscore a generally optimistic outlook on the impact of AI adoption in the SA construction industry. However, the variations in responses highlight the need for continued dialogue and consideration of specific ethical, societal, and safety implications associated with AI implementation in construction. Further research and practical initiatives may help address concerns and capitalize on the perceived benefits of AI in shaping the future of the construction sector in SA. The lack of government support, funding, technical expertise, trust, awareness, and cultural barriers collectively present a comprehensive set of challenges that stakeholders in the SA construction and civil engineering sectors must address collaboratively. To overcome these obstacles, industry leaders, policymakers, and educational institutions must work together to develop strategies, policies, and initiatives supporting responsible and effective integration of AI technologies in South African civil engineering projects.

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Annexures

DEAR RESPONDENT

INFORMED CONSENT TO COMPLETE SURVEY

You are invited to take part in a research study that forms part of a Master of Business Administration (MBA) degree. Please take some time to read the information presented here, which will explain the details of this study. Please ask the researcher or person explaining the research to you any questions about any part of this study that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research is about and how you might be involved. Also, your participation is entirely voluntary, and you are free to say no to participating, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part now.

This study has been approved by the NWU Economic and Management Sciences Research Ethics Committee (EMS-REC) and will be conducted according to the ethical guidelines and principles of the North-West University and other international ethical guidelines applicable to this study.

Title of the project: Assessment of the adoption of artificial intelligence (AI) in the South African construction industry

Institution: NWU Business School

Ethics Reference Number: NWU-00688-23-A4

Names and contact details of project staff

	Supervisor	Researcher
Title, name & surname	Dr Peit Pretorius	Mr Moleli Lumisi
Full Names		
Function in Project	Principle Investigator	Researcher
Telephone		0677337923

What is this research study all about?

The research is about the “Assessment of the adoption of artificial intelligence (AI) in the South African construction industry”.

What will be expected of you?

You will be expected to:

Complete the survey, which should take approximately 15 - 20 minutes of your time.

Respond to the questions in an open and honest manner.

Please note that your responses are completely anonymous and no personally identifiable data will be collected.

DECLARATION

Declaration by respondent

By selecting the option below, I agree to take part in the research study titled: The research is about the Assessment of the Adoption of Artificial Intelligence (AI) in the South African Construction Industry Economics.

I confirm that I have read the information sheet for the above study. I have had the opportunity to consider the information, ask questions, and have these answered satisfactorily.

I understand that as I have completed the study anonymously it will not be possible to remove any information I have provided, as you will not be able to identify me in any way.

I understand that individuals from the University may look at anonymous research data collected during the study, to ensure that the study is conducted appropriately.

I agree that my anonymous information can be shared with individuals from the project team detailed above.

I agree to take part in the above study.

Yes	No

1	2

SURVEY QUESTIONNAIRES

SECTION A: DEMOGRAPHIC INFORMATION

Please indicate the age group you fall under. (√ appropriate box)

21-30 years	
31-40 years	
30- 50 years	
50 years and above	

Please indicate your gender. (√ appropriate box)

Male	
Female	
Other (specify…………)	
Prefer not to say	

Please indicate your highest education level. (√ appropriate box)

National Diploma	
Bachelor's degree	
Postgraduate Diploma	
Honours Degree	
Master's degree	
Doctoral Degree	
Other	

Indicate your current job position at the organisation. (I think its best to rephrase this question into the years of employment to avoid confusion)

Entry-level	
Middle- level	
Senior-level	
Executive- level	
55 and over	

Please indicate your years of experience in the construction industry. (√ appropriate box)

3- 5 years	
6 – 10 years	
11- 15 years	
15 - 20	
21 years and above	

Please indicate the professional Council you have affiliated with. (√ appropriate box)

Engineering Council of South Africa (ECSA)	
South African Council for the Project and Construction Management Professionals (SACPCMP)	
Other	

Please indicate the size of your organization. (√ appropriate box)

Small (less than 50 employees)	
Medium (50-250 employees)	
Large (more than 250 employees)	

Please indicate the location of your organisation. (√ appropriate box)

Urban	
Suburban	
Rural	

SECTION B: QUESTIONAIRES

OBJECTIVE ONE SECTION B: **ARTIFICIAL INTELLIGENCE BENEFITS IN THE CONSTRUCTION INDUSTRY**

This section of the questionnaire identifies how has the use of artificial intelligence in the construction industry assisted civil engineering projects in South Africa

Kindly indicate your response using the provided five-Point Likert scale: 1= Never; 2 = Rarely; 3 = Sometimes; 4 = Always; 5 = Often

Indicate the benefits of the adoption of artificial intelligence in the South African construction industry.

S/N	**Artificial intelligence aids in the construction industry**	**Never**	**Rarely**	**Sometimes**	**Always**	**Often**
1	AI adoption can enhance the accuracy and quality of construction outputs.					
2	AI adoption can reduce overall costs in the South African construction industry.					
3	AI adoption can lead to more efficient use of resources in the construction industry.					
4	AI adoption can potentially improve safety standards and practices in the construction industry					
5	AI adoption requires significant financial investment for implementation in the construction industry.					
6	AI adoption may require upskilling and reskilling the workforce in the construction industry.					

7	AI adoption can contribute to a more sustainable construction sector in South Africa.					
8	AI adoption should be actively encouraged and supported by the government in the construction industry.					

OBJECTIVE TWO SECTION C: IMPACTS OF ARTIFICIAL INTELLIGENCE ON PRODUCTIVITY, COSTS, AND EMPLOYMENT IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

This section of the questionnaire investigates the impact of AI adoption on productivity, costs, and employment in the South African construction industry.

Kindly indicate your response using the provided five-Point Likert scale: 1= Never; 2 = Rarely; 3 = Sometimes; 4 = Always; 5 = Often

Indicate the impacts of AI adoption on productivity, costs, and employment in the South African construction industry.

S/N	**Artificial intelligence impacts productivity, cost and employment**	**Never**	**Rarely**	**Sometimes**	**Always**	**Often**
1	AI adoption in the South African construction industry will increase productivity.					
2	AI adoption in the South African construction industry will improve work quality.					
3	AI adoption in the South African construction industry will lead to cost savings.					
4	AI adoption in the South African construction industry will lead to job loss.					
5	AI adoption in the South African construction industry will create new jobs.					
6	AI adoption in the South African construction industry will improve safety.					
7	AI adoption in the South African construction industry will lead to better communication.					
8	AI adoption in the South African construction industry will lead to better visualisation.					
9	AI adoption in the South African construction industry will increase efficiency.					
10	AI adoption in the South African construction industry will improve project management.					
11	AI adoption in the South African construction industry will increase competitiveness.					
12	AI adoption in the South African construction industry will lead to increased innovation.					
13	AI adoption in the South African construction industry will increase customer satisfaction.					
14	AI adoption in the South African construction industry will lead to increased environmental sustainability.					

OBJECTIVE THREE SECTION D: THE ETHICAL AND SOCIETAL IMPLICATIONS OF AI ADOPTION IN THE SOUTH AFRICAN CONSTRUCTION INDUSTRY

This section of the questionnaire explores the ethical and societal implications of AI adoption in the South African construction industry.

Kindly indicate your response using the provided five-Point Likert scale: 1= Never; 2 = Rarely; 3 = Sometimes; 4 = Always; 5 = Often

Indicate AI adoption's ethical and societal implications in the South African construction industry.

S/N	**Ethical and societal implications of AI Adoption**	**Never**	**Rarely**	**Sometimes**	**Always**	**Often**
1	AI adoption in the construction industry can have ethical implications.					
2	AI adoption in the construction industry can have a societal impact.					
3	AI adoption has ethical implications for the construction industry.					
4	AI adoption in the construction industry impact employment opportunities					
5	AI adoption in the construction industry impacts the quality of work.					
6	AI adoption in the construction industry impact safety.					
7	AI adoption in the construction industry impacts the environment.					
8	AI adoption in the construction industry impacts the construction cost.					
9	AI adoption in the construction industry impacts the speed of construction.					
10	AI adoption in the construction industry impact construction accuracy.					
11	AI adoption in the construction industry impacts the reliability of construction.					
12	AI adoption in the construction industry can impact the privacy of construction workers.					
13	AI adoption in the construction industry impact construction site security.					
14	AI adoption in the construction industry impacts the trust between construction workers and AI systems.					

OBJECTIVE FOUR SECTION E: BARRIERS TO THE ADOPTION OF AI IN CIVIL ENGINEERING PROJECTS IN SOUTH AFRICA.

This section of the questionnaire determines the barriers to the adoption of AI in civil engineering projects in South Africa.

Kindly indicate your response using the provided five-Point Likert scale: 1= Never; 2 = Rarely; 3 = Sometimes; 4 = Always; 5 = Often

Indicate the barriers to the adoption of AI in civil engineering projects in South Africa.

S/N	**Barriers to AI Adoption in Civil Engineering**	**Never**	**Rarely**	**Sometimes**	**Always**	**Often**
1	There is a lack of awareness about AI in civil engineering projects in South Africa.					
2	There is a lack of technical expertise to implement AI in civil engineering projects in South Africa.					

3	There is a lack of funding for AI implementation in civil engineering projects in South Africa.					
4	There is a lack of government support for AI implementation in civil engineering projects in South Africa.					
5	There is a lack of trust in AI technology in civil engineering projects in South Africa.					
6	There are cultural barriers to using AI in civil engineering projects in South Africa.					