Construction Professionals' Awareness of Automation and Robotics in South Africa

Kurisani Mbhalati

A research article submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Business Administration

Johannesburg, 2024

DECLARATION

I, Kurisani Mbhalati, declare that this research report entitled "Construction professionals' awareness of automation and robotics in South Africa" is my own unaided work. I have acknowledged, attributed, and referenced all ideas sourced elsewhere. I am hereby submitting it in partial fulfilment of the requirements of the degree of Master of Business Administration at the University of the Witwatersrand, Johannesburg. I have not submitted this report before for any other degree or examination to any other institution.

Kurisani Mbhalati

Signed in Polokwane on 29 February 2024

Name of candidate	**Kurisani Mbhalati**
Student number	**1636189**
Telephone numbers	**078 188 1720**
Email address	kurisanimbhalati@gmail.com
First year of registration	**May 2019**
Date of final report submission	**29 February 2024**
Name of supervisor	**Dr Jenika Gobind**

ACKNOWLEDGEMENTS

I would like to extend my deepest gratitude to a number of individuals and organisations whose support was invaluable during the course of this research project.

First and foremost, my sincere thanks go to my supervisor, Dr. Jenika Gobind, for her unwavering guidance, insightful feedback, and continuous encouragement throughout this journey. Her expertise and dedication have been fundamental in shaping this work, and her mentorship has been a cornerstone of my academic development.

I am also immensely grateful to my employer, Roads Agency Limpopo, for their generous funding of my studies. Their support not only underscores their commitment to advancing knowledge and professional development but also enabled me to pursue this research with the necessary resources and focus.

Moreover, I must express my sincere appreciation to the research participants who took their valuable time to respond to the survey. Their willingness to share their experiences and insights has been crucial to the success of this project, and their contributions are greatly acknowledged.

Furthermore, I wish to express my heartfelt appreciation to my friends and family. Their constant support, understanding, and encouragement have been a source of strength and motivation. Their belief in my abilities and their unwavering presence have been a guiding light throughout this challenging but rewarding endeavour.

To everyone who played a part in this journey, your contributions have left a permanent mark on my work, and for that, I am forever thankful.

ABSTRACT

In South Africa, the construction sector, which accounts for approximately 3% of the GDP, is essential for economic growth but struggles with issues such as falling productivity, quality concerns, and safety risks. The adoption of robotics and automation could address these challenges, offering more reliable and precise quality, boosting productivity, cutting costs, and increasing safety by automating dangerous tasks.

This cross-sectional study aimed at assessing the awareness of automation and robotics among South African construction professionals through a quantitative survey. Additionally, the research sought to capture the professionals' opinions on the benefits these technologies could offer to construction projects and identify the barriers to their wider adoption as perceived by these professionals.

Findings indicated a varied level of awareness among construction professionals, with high familiarity in technologies like Computer-Aided Design (CAD) and lower awareness in emerging technologies such as Virtual Reality (VR). Moreover, the professionals acknowledged the benefits of adopting these technologies, notably highlighting increased productivity and safety as key benefits. They also identified significant barriers to adoption, citing high acquisition costs and socio-economic concerns over job displacement as major obstacles, particularly in a context of high unemployment rates.

Considering the construction industry's role in economic growth and recognizing the dip in productivity, alongside the industry's reluctance towards innovation, the study recommends focused educational initiatives and promotional activities for robotics and automation. It further stresses the need for policy changes to ensure the safe and efficient implementation of these technologies. Moreover, from a governmental standpoint, the study suggests providing incentives to businesses to encourage the adoption of robotics and automation in the construction industry.

Keywords: Robotics, automation, construction, awareness, barriers, benefits

Table of Contents

LIST OF ABBREVIATIONS

CIDB	Construction Industry Development Board
GDP	Gross Domestic Product
CAD	Computer-Aided Design
BIM	Building Information Modelling
GPS	Global Positioning System
JSE	Johannesburg Stocks Exchange
RFID	Radio Frequency Identification
VR	Virtual Reality
HMD	Head Mounted Display
DOI	Diffusions of Innovation
UAV	Unmanned Aerial Vehicle
IFR	Internation Federation of Robotics
IAARC	International Association for Automation & Robotics in Construction

LIST OF FIGURES

LIST OF TABLES

1. CHAPTER 1: INTRODUCTION

1.1. Introduction

This segment starts off by providing background information. This is crucial for situating the research within its broader context and helping the reader understand the starting point of the study. The research's objectives or goals will be summarised in a statement of purpose. This will give the reader a quick overview of what the study aims to achieve. The study’s research questions, which are closely tied to its purpose, will be outlined. These questions were central to guiding the research process and are intended to be answered through the findings of the research. A section has been dedicated to defining key concepts and terms used in the study. This will enable readers to appreciate the specific meanings of terms as they are used in this research. The significance of the study will be discussed, explaining why the research is important and what it aims to contribute. Additionally, this chapter will define the study’s limitations, which are the constraints or boundaries that delineate the extent of the research.

1.2. Background of the study

For over 4500 years, construction has evolved from Mesopotamia's primitive firebrick to Egypt's advanced cut-stone structures, highlighting the progress of human civilisation (Bruner, 2007). Early human settlements grew from small villages into bigger towns and cities, leading to higher quality and durable structures. The construction industry developed as the cities and towns required services like roads, bridges, and communication infrastructure (Hughes & Hillebrandt, 2003). Today, the industry consists of companies and individuals engaged in the design, procurement, building, maintenance, and demolition of various structures.

The growth of emerging economies in developing nations remains contingent upon the productivity of the construction sector (Paul & Vogl, 2006). When the construction industry performs well, it can boost the economy of these countries.

Governments are important players in the construction sector, especially as major clients for large projects. Their involvement in projects impacts not just the construction industry, but also the broader economy (Ofori, 2015). This implies that government decisions and investments in construction can have wide-reaching economic effects.

In highlighting the construction sector's meaningful contribution to the world economy, Stojanovska-Georgievska et al. (2021) indicated that it contributes about 6% to the global GDP every year. Construct Africa (2022) reports that approximately 3% of South Africa's GDP is represented by the construction sector. The industry experienced significant growth after the end of apartheid, which had previously hindered the industry's expansion due to racial discrimination and sanctions (Cottle, 2014)

However, the CIDB (2015) has noted a concerning decrease in productivity across the construction sector in South Africa. This worrying decline suggests that the efficacy and output of the sector is reducing. In contrast, productivity in the manufacturing industry doubled over the last few decades (Changali, Mohammad & Niewland, 2015). Serious difficulties are being experienced within South Africa's construction sector. Group Five, once a leading construction company in South Africa, faced severe financial troubles and underwent business rescue in 2019. Subsequently, it was delisted from the JSE (Labour Research Service, 2020).

The sector is dealing with significant issues like poor product quality and increasing health and safety hazards (Akinradewo et al., 2018). As such construction sites are not meeting expected quality standards, and there are growing concerns about the safety of workers. Smallwood (2007) highlights that, unlike other industries, the construction sector is particularly dangerous. In justifying this point, the author notes the large number of people who have suffered injuries or fatalities on construction sites.

Mahbub (2012) argues that the drive for innovation in most countries is primarily fuelled by the need to find creative solutions to various challenges such as skills shortages, deteriorating product quality, poor working environments, falling productivity, and escalating expenses on labour and materials. Supporting this notion, Tangkar and Arditi (2000) contend that the unique characteristics of a problem extensively influence the formulation of a creative solution. Despite these insights, the construction sector lags in adopting innovative technologies that could enhance safety, productivity, and quality. Paradoxically, even though the industry heavily depends on machinery, it remains one of the least digitised sectors, as noted by Barbosa, Woetzel & Mischke (2017).

Worldwide, there is a rising appreciation for robotic systems. This is evident in the form of global investment on robots. The International Data Corporation (2020) estimated that a total of $128.7 billion was spent on robotics systems and drones in 2020 alone. The International Federation of Robotics (2020) conducted research revealing that over the past four decades, the number of operational robots has increased by more than 100 times, reaching an estimated 3 million.

Robots dominate the metal and automobile industries where they have been widely deployed to perform a variety of activities such as welding and assembly (Graetz & Michaels, 2018). Lexus, the famous car brand, started manufacturing cars on a fully automated and robotised assembly line in the year 2000 (da Silva, Eloy & Resende, 2022). The continuous growth of the enlistment of robots, especially within the automobile sector, stems from the need to lift heavy objects and shortening production times (Seliger, 1988).

1.3. Problem statement

The South African construction industry has the potential to significantly improve various aspects of its operations through the adoption of construction automation and robotics, as suggested by Akinradewo et al. (2019). However, there is a notable conservatism within the industry, as highlighted by Tatum (1984), which results in a slow adoption of innovative technologies. Kuczmarski (1996) argues that successful technological adoption requires an ongoing commitment to new ideas and a forward-thinking approach.

Despite the numerous benefits identified by Elattar (2008), such as improved quality, enhanced productivity, reduced costs, and increased safety through the use of robotics and automation, the South African construction sector remains cautious. This contrasts with the manufacturing sector, where automation and robotics have been widely adopted and have led to significant productivity gains, as noted by Graetz and Michaels (2018) and others.

Studies by Akinradewo et al. (2018) and Bock (2008) indicate a high level of eagerness among South African construction professionals to embrace these technologies, yet barriers to adoption persist. This research seeks to address the problem of understanding the underlying reasons for the slow adoption of robotics and automation in the South African construction industry, despite the evident benefits and the willingness of professionals to adopt these technologies.

1.4. Statement of purpose

The aim of this research, firstly, is to broadly assess the level of awareness among South African construction professionals regarding the use of robotics and automation within the industry. The information gathered about the professionals' awareness can act as an initial step in exploring why these technologies are not being widely adopted or used by construction companies. The idea is that by first determining how familiar the industry is with automation and robotics, the study can then investigate the reasons behind the limited use of these technologies.

Secondly, the research seeks to discover and highlight the benefits that robotics and construction automation can offer. This involves exploring how these technologies can improve various aspects of construction projects. Construction professionals, who oversee the running of construction projects, make important decisions about how projects are built, what materials are used, the quality of the work, and how much it costs. The successful implementation and widespread adoption of construction automation and robotics largely depend on these construction professionals. For these technologies to be adopted into the industry, the professionals overseeing construction projects need to understand and value the benefits that these technologies offer.

Lastly, the study aims to uncover and emphasize the existing challenges or barriers that prevent or slow down the integration of robotics and automation within the construction sector. This involves identifying specific issues or difficulties that companies face when considering the application of these technologies. Beyond just identifying these barriers, the study seeks to understand how significant these obstacles are in preventing the adoption of these technologies. By revealing and understanding these barriers, the study hopes to enable construction professionals to devise strategies and solutions to overcome them. This could involve developing new approaches or modifying existing practices.

1.5. Research questions

Centred on three research questions, this research explores different aspects concerning the utilisation of automation and robotics within the construction sector. The research questions form the foundation of the study - steering and shaping its breadth:

1. **What is the level of awareness of the existing types of robotics and construction automation currently in use in the construction industry?**

- This question seeks to gauge the current understanding among South Africa construction professionals about the types of robotics and automation technologies being utilised in the industry. It aims to uncover the degree of knowledge and familiarity these professionals have with these technologies.
- ***H1:*** There are significant differences in the awareness of robotics and construction automation technologies among South African construction professionals based on their demographic characteristics (gender, age, educational qualifications, job title, work experience, and type of employer)

2. **What are the perceived benefits of adopting the use of robots and automation in the South African construction industry?**

- The focus here is on identifying the positive aspects and potential benefits perceived by industry professionals regarding the implementation of automation and robotics. Understanding these perceived advantages is crucial for recognising the factors that may stimulate the widespread usage of these technologies.

3. **What are the perceived barriers to adoption of robotics and automation in the South African construction industry?**

- The question delves into identifying and understanding the challenges, obstacles, or concerns that might hinder or dissuade construction companies in South Africa from adopting these technological advancements. Recognising these barriers is essential for developing strategies to overcome them and facilitate wider acceptance of automation and robotics in the sector.

1.6. Definitions of terms

This section provides definitions of key concepts, enabling readers to better comprehend the material presented in the upcoming chapters.

Automation:

Automation – "a system performing parts, or all, of a task that was, or could have been, performed by humans" (Douer & Meyer, 2020, p. 2)

Automation – "a process or specific task-oriented system that operates without immediate human control" (Hong, 2020, p. i)

Automation – "the use of control systems and information technologies to scale back the necessity for human work" (Mhaisalkar, Chaudhari & Kawale, 2020, p. 134)

Robotics:

Robotics - “reprogrammable, multifunctional manipulators designed to move materials, parts, tools, or specialised devices through programmed motions for the performance of a variety of tasks” (Robot Institute of America, 1979)

Robotics - “a branch of technology that deals with robots” (Adingani, 2020, p. 4)

Construction Automation:

Construction automation – “the work to increase the contribution of machines or tools while decreasing the human input” (Tucker, 1988, p. 9).

Construction automation – “performance of any construction process, on-site or off-site, by means of teleoperated, numerically controlled, semiautonomous, or autonomous equipment” (Skibniewski, 1992, p. 17)

Robot:

Robot – “an autonomous system which exists in the physical world, can sense its environment, and can act on it to achieve some goals” (Shamsuddin et al., 2012, p. 1450)

Awareness:

Awareness – “the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (Endsley, Onal & Kaber, 1997)

Benefit:

Benefit – “an outcome whose nature and value are considered advantageous by an organisation” (Yates et al., 2009, p. 224)

Barrier:

Barrier – “a problem, rule or situation, obstacle that prevents someone from doing something or that creates difficulty to implement” (Mehfooz & Lodhi, 2015, p. 69)

1.7. Significance of the study

Aghimien et al. (2019) executed a scrutiny into the amount of research done on automation and robotics and found a noticeable lack of such research, especially in Africa. This is concerning because there is a pressing need to gain comprehensive insights into their utilisation in the building industry. This scholarly effort broadens the existing pool of literature by identifying and classifying current automation and robotic innovations used in the construction sector.

Given the restricted utilisation of robotics and automation in South Africa's building sector, it is apparent that further studies and dialogue are required to understand the barriers to their adoption. This research fills this void by giving a detailed overview of the difficulties experienced in adopting robotics and automation within the sector. The study also serves as an attempt to inspire industry decision-makers to consider adopting automation and robotics by outlining the advantages they offer.

1.8. Delimitations of the study

The research’s geographical scope is confined to South Africa’s Limpopo province. Limiting the study's focus to Limpopo province may reduce the relevance of the findings to other regions with different economic, cultural, and technological contexts. The sample size of the construction professionals and its representativeness could limit the findings. The sample consist of 44 participants. It may not fully capture the views and experiences of the broader industry.

Responses from construction professionals may also be subjective and influenced by personal experiences and biases. This could affect the objectivity of the data collected on awareness, benefits and barriers of robotics and automation. The rapid evolution of innovations in automation and robotics means that the findings may become outdated quickly. Technologies and their applications in construction could evolve significantly, even over a short period.

1.9. Summary

The chapter begins with a high-level overview of the research, designed to familiarise readers with the core themes and objectives of the study. It strategically prepares the audience for the detailed exploration to come, effectively laying the groundwork. Following this introduction, the next chapter delves into an in-depth literature review focused on the topics of construction automation and robotics.

2. CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

This section furnishes a historical context, tracing the evolution of automation and robotics in the building sector. This is to showcase the advancement of these technologies over time. A brief overview of available literature concerning the awareness of automation and robotics within the building sector is offered, highlighting the scarcity of research in this domain. The narrative then shifts to discuss the types of automation and robotic technologies currently used in the building industry, shedding light on their applications and importance. An extensive analysis of both the benefits and the barriers associated with these technologies is conducted, providing a balanced view of their impact. The chapter closes off by outlining the conceptual and theoretical frameworks on which this research is grounded.

2.2. History of automation and robotics in the construction sector

The history of automation and robotics in the building industry unfolds as a tale of global innovation, characterised by technological developments and a shift toward a new era of construction methodologies.

Bernold (1987) predicted more than 30 years ago that smart machines would likely become a part of the construction sector. He foresaw that the construction industry was a promising area where robots could be used but had not been explored much yet. Mirjan et al. (2016) also agrees that conventional construction practices will be replaced by robotic construction, aligning the construction industry with the technological sophistication found in other advanced sectors like manufacturing.

The construction industry underwent four stages of evolutionary change, according to Hason (1994). The changes are described as evolutionary due to the long time it took for them to occur, unlike revolutionary changes that happen almost always instantly. According to Hason (1994) the first stage in the evolution of construction was the introduction of mechanisation. Machines brought raw power into activities such as material handling and lifting. Second, prefabrication meant that structural components could be mass-produced in factories, thereby reducing human resources requirements. Construction entered its third stage of evolution with the introduction of new materials. These new materials made it cheaper and convenient to build structures. And lastly, breakthroughs in microelectronics set the stage for the electronic control of construction machines which then paved the way for construction automation and robotics.

Gharbia et al. (2020) summarised the evolution of site-based robots by decade as depicted in Figure 1 below.

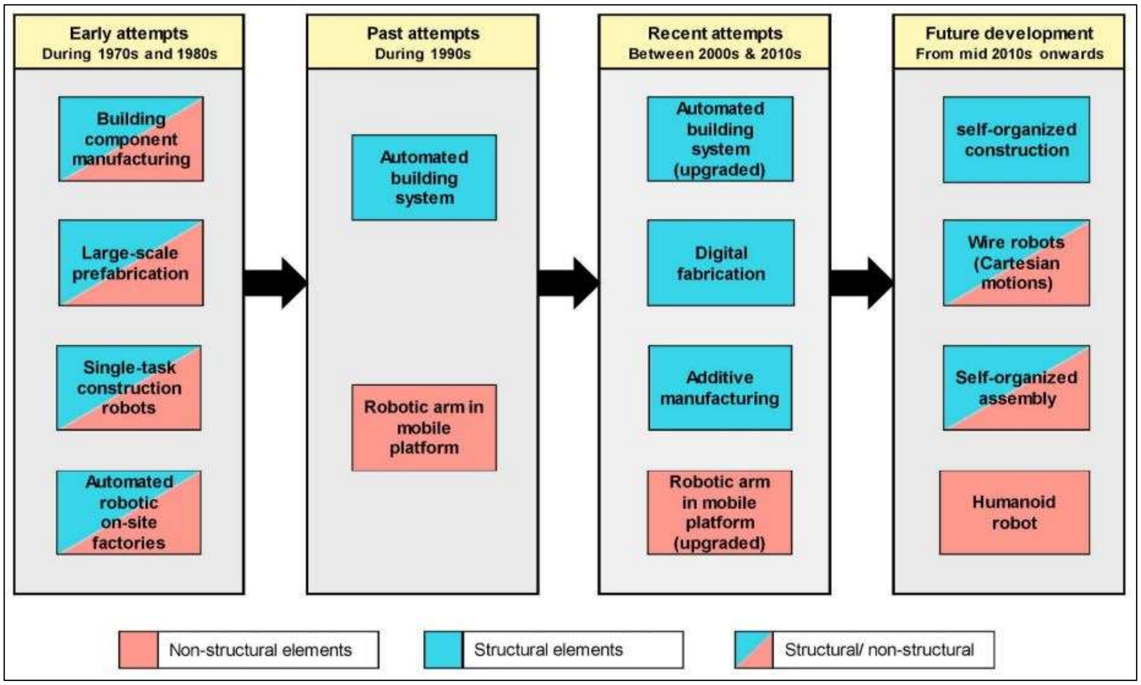

Figure 1 – The evolution of site-based robots (Source: Gharbia et al., 2020)

Figure 1, as proposed by Gharbia et al. (2020), offers a summary of the progression and milestones in the field of construction automation and robotics, tracing its development from the 1970s and projecting into the future. In the early attempts of the 1970s and 1980s, the industry witnessed the inception of single-task construction robots and large-scale prefabrication, which represented the first steps toward automating the construction process. The 1990s were marked by the introduction of robotic arms mounted on mobile platforms, reflecting an advancement in the mobility and adaptability of robotic systems within construction environments. Recent attempts between the 2000s and 2010s incorporated additive manufacturing and digital fabrication. Looking towards the future, from the mid-2010s onwards, the chart anticipates a revolutionary transition to self-organized construction. The introduction of humanoid robots envisions a future where robots with human-like capabilities could navigate construction sites.

After World War II, the advancement in computing technology facilitated the emergence of more sophisticated automation systems in manufacturing - such as the assembly of automobile parts (Mahbub, 2012). Around this time, large

Japanese contractors began their involvement in the research and development of construction robots (Morales, Herbzman & Najafi, 1999). Many authors support the notion that automated construction was birthed in Japan. However, there are disagreements in terms of timelines.

Hatoum and Nassereddine (2020) claim that Japan began research into the concept of construction automation in 1970 after observing decreasing productivity growth rates in the construction industry. Japanese construction firms became industry leaders in construction robots' development and research. For example, Shimizu Corporation designed and built robots for concrete cutting, concrete floor finishing, ceiling panel positioning, exterior wall painting, and fireproofing (Kangari & Yoshida, 1990).

According to Darlow, Rotimi and Shahzad (2021) Japan is widely recognised as a global frontrunner in the field of building automation. Zuk (1985) attributed Japan's success to its government, which took an aggressive stance in developing construction robots. Japan’s Ministry of Construction encouraged and funded research into the design, building and maintenance of construction robots.

Japan allocated funding to robotics hardware research through programs such as ART (Advanced Robot Technology), ACT (Advanced systems for Construction Technologies) and WASCOR (WAseda university Construction Robot) (Albus, 1986). Besides government subsidies, Japanese construction firms such as Takenaka, Obayashi and others also showed their commitment to further the development of robotic systems by spending approximately 1% of their gross revenues on R&D activities (Zuk, 1985).

As far back as the 1960s, Europe also advanced construction automation in how they mixed concrete and asphalt (Poppy, 1994). The development of microelectronic control devices gave construction machinery and equipment a boost. These control systems were able to constantly notify the operator about the machine's state for better optimisation to suit site conditions (Poppy, 1994). Between 1989 and 1995, Sweden launched a pilot project aimed at developing prototypes for applying robotic technology in diverse conditions found in outdoor construction sites (Hoeft et al., 202).

Since the early 1980s, the construction industry had started to look at adapting robotics and automated techniques (Hsiao, 1994). In the United States, activities related to construction automation were firmly focused on software development and research rather than hardware development and design (Skibniewski, 1992). Hoeft et al. (2022) say that advancements in computer software and hardware pushed the boundaries of what robots can do, making them more autonomous and versatile in a wide range of applications. By the 2000s, humanoid robots started appearing on construction sites for various applications such as operating forklifts and carrying heavy objects like concrete slabs (Bock, 2015).

Collective efforts from multiple countries resulted in establishing the IAARC (International Association for Automation and Robotics in Construction) in 1985. Its primary goal as an organisation is to gather and disseminate information related to advancements in the fields of robotics and automation as they apply to the building sector (Hoeft et al., 2022). This effort helps to keep professionals across the globe informed about the latest trends, technologies, and research findings.

2.3. Awareness of construction automation and robotics

After thoroughly examining available literature, the researcher identified only two studies specifically addressing the awareness of automation and robotics within the building sector. The first research paper, written by Fadamiro and Oke (2019) in Nigeria, revealed that the most recognised automation technologies among construction professionals there were Building Information Modeling (BIM) and Computer-Aided Design (CAD). Similarly, a research paper by Akinradewo et al. (2021) in South Africa (Gauteng province), reported comparable findings, with BIM and CAD being the most familiar to construction professionals in the region. Both studies employed quantitative methods, mirroring the approach of this research, where participants rated their awareness on a spectrum - from very high to very low.

In other research, like the works of Cai, Skibniewski & Bao (2019), Pradhananga et al. (2021), and Mahbub (2008), a common finding is that low awareness of automation and robotics acts as a serious obstacle to their adoption. This underscores the idea that understanding the level of awareness within the building sector is a crucial step towards facilitating the integration of these innovations.

2.4. Types of robotics and automation in the construction sector

According to Delgado et al. (2019) there is no agreement amongst researchers on how to categorize the many kinds of automated and robotic technologies used in the building sector. Mahbub (2008) believes that automation and robotics have a wide-ranging application throughout the full timeline of a building project. This starts with the initial design stage to the real-world on-site construction. The author’s argument suggests that automation and robotics can enhance various stages of construction. Nevertheless, Galic (2022) highlights a difference in perspective between designers and contractors on the use of automation and robotics - designers tend to view it as it relates to planning and design, whereas contractors view it as automating construction activities at the project site.

Kim et al. (2015) advocate for an integrated approach where automation is not an afterthought but a foundational element of both planning and execution stages. Bock (2012) also emphasizes the need for architects and engineers to consider the use of robotics right from the initial design stages of a structure. This means that when planning and designing buildings or other construction projects, the capabilities and limitations of robotic construction methods should be considered. It must be ensured that the design of the structure facilitates the use of robots in its construction.

2.4.1. Building Information Modelling (BIM)

Various researchers define the primary purpose of BIM in different ways. According to Chea et al. (2020) the usage of BIM aims to enhance construction administration through digitalisation of construction information such as drawings and reports. Eastman et al. (2011) see BIM as a platform where project stakeholders collaborate, across the entire project duration, by inserting and extracting information.

For a long time in construction, paper drawings offered a reliable way to communicate, and were used for sharing information about the design of buildings (Turk, 2016). However, with the advent of innovative technologies, computer software became the new standard for planning and designing construction projects. Early on, the software was based on 2D geometric shapes until it matured into 3D objects. This transition, from CAD to BIM, allowed modellers to represent buildings as dynamic digital objects (Turk, 2016).

A contributing factor to the underperformance of building projects is the inability to cope with bulk and intensive information (Crotty, 2013). Inherently, construction projects draw numerous professionals from several organisations to cooperate in carrying out the project scope. A BIM model allows information exchange to smoothly take place amongst all project team members such as engineers, project managers, designers, transporters, and others (Al-Ashmori et al., 2020).

Most construction automation activities, such as prefabrication and remotely operated vehicles, are powered by BIM (Ibrahim, Hashim & Jamal, 2019). By 2025, BIM is expected to yield time and cost savings of between 13% and 21% during the planning and construction stages of construction projects (Dodge, 2017). Embracing the move to digitalization will greatly facilitate amplifying the performance of the construction sector (Agenda, 2016).

According to Ullah, Lill and Witt (2019) there has been a meaningful adoption of BIM throughout the globe, especially in developed nations. At the forefront is the United States of America through their National 3D-4D program, which stipulated the utilisation of Building Information Modelling in all government funded building projects. The United Kingdom is also a major adopter of BIM, with roughly 70% of all construction professional using BIM (Burgess, Jones & Muir, 2018).

2.4.2. Off-site prefabrication automation

Jiang et al. (2018) define off-site construction as a building methodology that occurs at an isolated place, removed from the construction site, to guarantee that construction activities are performed in a controlled setting. This entails the automated manufacture of construction components at a remote facility utilizing robots and machinery, which are subsequently hauled to the project site for installation (Darlow, Rotimi & Shahzad, 2021).

The logistical element of transporting the prefabricated components from factories to sites may also be automated (Yin, Chen & Li, 2016). The chosen mode of transportation mainly depends on the extent of the haulage distance. Road, sea, rail, or air transportation are some of the preferred options. The automation of trains had been achieved by the 1970s and most countries today have adopted automatic train operation (Yin, Chen & Li, 2016). Similarly, ships already use automated systems such as GPS and collision-avoidance to safely navigate invisible ocean routes (Kijima & Furukawa, 2003). Roads are generally the most used transportation mode. Innovative car companies like Tesla are at the forefront in terms of developing autonomous driving systems (Endsley, 2017). These systems generate real time information for status and location tracking.

2.4.3. Drones

Josephson and Hammarlund (1999) claim that the construction industry loses about 12.4% of project budgets to reworking defects on construction sites. Construction monitoring plays a critical role in minimising human errors that lead to construction defects, with the goal of providing quality products that meet all expectations of project stakeholders (Bohn, 2009). Visual inspection is an economical and non-destructive methodology used to assess the physical condition of engineering structures and buildings (Kopsida & Brilakis, 2015).

Rakha and Gorodetsky (2018) claim that drones are primarily used for conducting aerial surveys and construction monitoring purposes. For example, drones have been utilized to autonomously perform visual inspections of bridges (Peel et al., 2018). Other terms are employed to denote drones in literature and regulatory documents, these include UAV (Unmanned Aerial Vehicle), UAS (Unmanned Aircraft System) and RPAS (Remotely Piloted Aircraft System).

According to da Silva et al. (2022) drones have two modes of operation. They can either be controlled in real-time by an individual using a remote control, or they can operate autonomously by following pre-programmed routes utilising sophisticated electronic control devices like GPS, radars and sensors.

Falorca, Miraldes and Lanzinha (2021) also demonstrated that drones can effectively perform the visual inspection of engineering structures. The researchers employed drones to inspect the general condition of a curtain wall of an 18-floor residential building and a clay brick chimney in Portugal. The drones were fitted with a high-definition camera to record videos and capture images of the various elements of the structures. A pre-determined flight path was followed to ensure that the entire surfaces of both structures were fully inspected for damages. In terms of data analysis, the video recordings were evaluated and even played back in slow motion when required. The clarity of the visuals revealed details that would have been difficult to detect with the human eye. Drones demonstrate a significant advantage in manoeuvrability where areas to be inspected are inaccessible to a human worker. There is also a cost benefit since the need for scaffolding is eliminated when inspecting tall structures.

2.4.4. Sensing Technologies

Efficiently managing of construction processes depends crucially on the timely availability of precise and dependable onsite information (Moselhi, Bardareh & Zhu, 2020). Instant feedback from real-time information helps in monitoring project activities. Omar and Nehdi (2016) claim that traditional approaches to obtaining data can be a time-consuming and laborious process that may not always yield precise results. The collection of this data at the construction site can be automated instead of using conventional data acquisition methods.

Sensor-based technologies are regarded as a cutting-edge approach to gathering and managing information. Prior to the mid-2000s there was a limited use and a narrow scope of application of sensor-based technologies (Zhang, Cao & Zhao, 2017). Since then, the application of sensing technologies for enhancing construction management has emerged as a rapidly evolving domain of interest among the engineering and academic circles (Zhang, Cao & Zhao, 2017).

There are various types of sensors available in the market. When selecting these sensors, several factors come into play, including the desired information and the environmental conditions in which the data will be gathered.

Location sensors

During construction, materials and workers are in constant motion. Controlling their movements can lead to increased efficiency and enhanced safety (Valero, Adán & Cerrada, 2015). Wireless sensors can help identify materials and estimate their location in a construction site (Yagi, Arai & Arai, 2005). The two most common location sensors the author found in the reviewed literature were RFID and GPS.

Domdouzis, Kumar and Anumba (2007) noted that RFID stands for radio frequency identification. The functioning of RFID relies on the transmission of data through electromagnetic signals. RFID utilises radio signals for the identification of specific targets (Calis et al., 2011). This technology comprises of tags, readers, and antennas. The antenna and a set of tags, which store information, are connected to the reader (Valero et al., 2015). RFID tags are attached to material components, like steel beams and concrete panels, on a construction site to keep track of where they are (Grau, Zeng & Xiao, 2012). Pipe blockage in a drainage system can be checked by running through balls with RFID tags. In Figure 2 below, a visual representation of an RFID setup is shown.

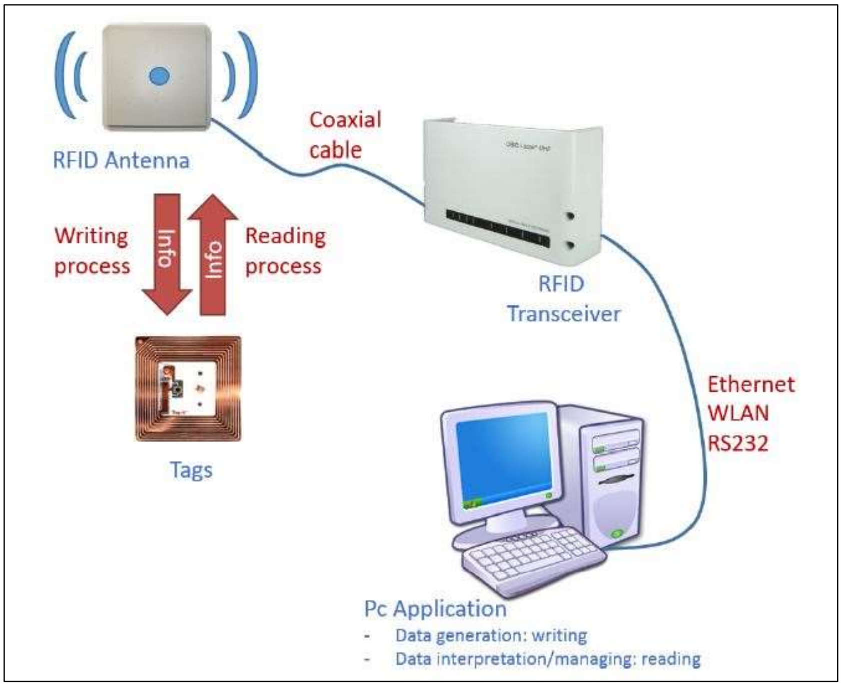

Figure 2 – A typical RFID system (Source: Valero et al., 2015)

The Global Positioning System (GPS) sends signals containing positioning data to a receiver that is affixed to an object situated on the surface of the Earth, such as a construction vehicle (Li, Chan & Skitmore, 2013). The receiver uses this information to compute the object's location and orientation. Nevertheless, and in contrast to RFID, applying GPS for indoor tracking is difficult because the signals from space satellites may be obstructed (Li, Chan & Skitmore, 2013).

Vision sensors

The process of vision-based sensing involves the use of imaging sensors to capture photos or videos, which are subsequently processed with specific algorithms to gain an understanding of the environment (Gu, Lo, & Niemegeers, 2009). However, this approach is susceptible to environmental variables like background colour and lighting conditions, which may impact its effectiveness (Gu, Lo, & Niemegeers, 2009).

Yan et al. (2018) developed a quality inspection and assessment robot for buildings called QuicaBot. QuicaBot is a mobile robot which consists of both thermal and colour cameras, an inclinometer and a 2-D laser scanner. The robotic system performs a comprehensive scan of a room in a building to autonomously detect construction defects such as cracks, unevenness, hollowness and misalignments. Yen et al. (2015) demonstrated that QuicaBot offers better accuracy and speed over a human inspecting the same room.

Leung, Mak and Lee (2008) developed a live interconnected communication system for quality and progress monitoring of project activities. The system is a cost-effective combination of cameras, wireless routers, antennas, and a web platform. It permits authenticated users to receive live data related to the state of the construction site, worker behaviour and physical progress of the works. The system is collaborative in nature, it allows users to log in via the internet to view and discuss site events.

2.4.5. 3D printing

El-Sayegh, Romdhane and Manjikian (2020, pg. 4) state that "3D printing is an automated process that produces complex shape geometries from a 3D model (computer-aided design model) on a layer-by-layer basis, through a series of cross-sectional slices". Figure 3 by Nadarajah (2018) below, compares the differences between conventional construction and 3D printing construction.

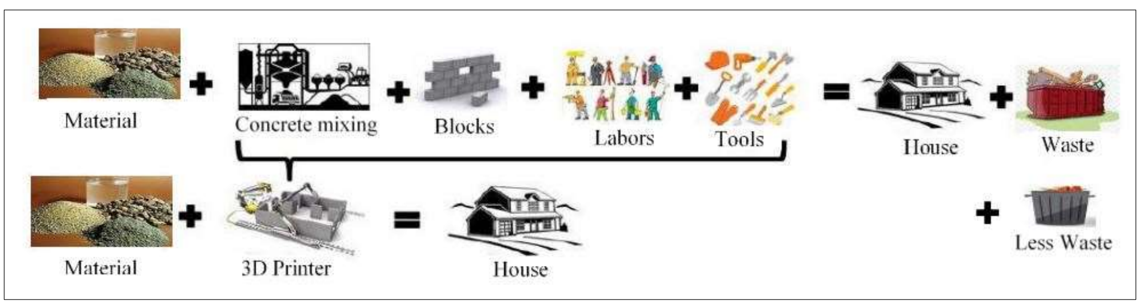

Figure 3 - Comparison of conventional and 3D Printing construction (Source: Nadarajah, 2018)

As a construction material, concrete is preferred for 3D printing thanks to its ink-like fluidity and drying quickness (Wu, Zhao, Baller & Wang, 2018). A vast majority of civil engineering structures are built using concrete. 3D printing eliminates the need for formwork in creating complex shapes of structural elements. Instead, intricate geometries are autonomously printed layer-by-layer from a CAD model in the absence of human interference and conventional tools (Nadarajah, 2018).

Proverbs, Holt and Olomolaiye (1999) claim that the usage of formwork in concrete construction accounts for 25% to 35% of the costs and execution time. It can then be said that 3D printing carries the enormous capacity to lower construction costs, waste and duration. Chen et al. (2018) supports the notion that 3D printing construction promotes preservation of the natural environment due to reduced waste generation. This technology is shifting the paradigm in terms of how construction components are built, even though it has not reached a level of industry-wide adoption (Smith, 2012).

2.4.6. Robotic manipulators

Robotic manipulators are commonly installed at a fixed location, particularly in manufacturing assembly lines. However, they can also be affixed to a movable platform. For large-scale construction purposes, mobile robotic manipulators that can accurately determine their position within a workspace are better suited (Mascaro et al, 2020).

Robotic arms are manipulators, consisting of rotational segments, that can be precisely controlled through programming to perform specific movements. Imitating the performance of human arms, robotics arms are capable of performing a significant range of movements (da Silva et al., 2022). A tool, such as a drill, claw, or suction cup, may be attached to the end of robotic arms to manipulate objects.

Mascaro et al. (2020) presented an autonomous robotic excavator equipped with advanced features that enable it to accurately perceive and map the intricate and unorganized surrounding environment. This robot is one of the few which can isolate and manipulate irregular objects, like stockpile of rocks in a natural setting on site. For remote and isolated projects, such as stone pitching for river erosion protection works, this type of robotic excavator is best suited for manipulation of the naturally occurring stones.

Jud, Leemann, Kerscher and Hutter (2019) demonstrated that an excavator fitted with autonomously controlled hydraulic joints could reliably dig a trench using ground geometry data fed directly from CAD models.

2.4.7. Construction simulation with Virtual Reality

Virtual Reality technology traces its origins back to the aerospace and defence industries, where the flight simulator was developed. The initial application of VR in construction was in the development of walkthrough systems (Bouchlaghem, Thorpe & Liyanage, 1996). Lucas (2020) stated that virtual reality (VR) is an interactive 3D virtual world created through computer simulation. Virtual Reality technology offers the illusion of being actively engaged in a simulated environment, as opposed to passively observing it from an external perspective.

By utilizing an HMD (Head Mounted Display), Immersive VR offers a feeling of existence within a virtual environment, even though the user is physically located elsewhere (Lucas, 2020). An immersive virtual environment is a system that envelops or encloses the user within an environment, thereby providing a sense of being present in a real-life setting (Bouchlaghem et al., 1996). In such an environment, the user may feel as if they are in a natural environment.

Garrett and Teizer (2009) widely acknowledge that human error is a significant factor in many occupational injuries within the construction industry. Even with the progress made in implementing improved safety regulations, there hasn't been a noteworthy decrease in the frequency of construction accidents (Rokooei et al., 2023). This has prompted researchers and safety professionals to seek out more innovative approaches to tackle this problem. Various researchers (Hilfert et al., 2016, Le et al, 2014 and Pedro et al., 2016) have explored the application of VR and 3D simulation in the realm of construction safety.

Ensafi et al. (2021) are of the belief that VR (Virtual Reality) offers a novel way to train construction workers while minimizing the risk of accidents. Through realistic simulations of hazardous environments, VR can fully immerse users in computergenerated scenarios. For example, it holds promise as a helpful tool for training high-rise construction workers, as it eliminates the dangers associated with falling (Ergun, 2015).

Li et al. (2018) state that safety training is typically conducted to enhance individuals' ability to identify potential hazards. In this regard, Ahemd (2018) suggests that visualization technologies may enhance safety training through the use of virtual exercises that facilitate construction project safety. Specifically, virtual reality (VR) technology enables quick and responsive feedback to user manipulations. Parvinen, Hamari, and Poyry (2019) note that various instructions, sent through sound, speech, position, or movement, can be easily processed by VR models - further enhancing the effectiveness of this technology. The advantages of VR, including its repeatability and customization, make it a highly desirable and viable option for construction safety training.

In 2013, Sacks, Perlman and Barak demonstrated that employing cutting-edge virtual reality (VR) techniques for safety training proved to be more efficient in recognizing and evaluating safety hazards in buildings than standard safety training methods. Typically, classroom-based construction safety education is delivered using slide presentations or videos, as noted by Wang et al. (2018). Nonetheless, Guo, Yu and Skitmore (2017) have suggested that virtual reality offers an engaging and authentic option as compared to training methods that rely on videos or printed materials.

A VR training program focused on construction safety for roofing workers was developed by Rokooei et al. (2023). The study aimed to examine how roofing professionals viewed the adoption of virtual reality in safety education. The findings of the study showed that exposure to VR education yielded positive results for industry practitioners. Additionally, the authors discovered that accidents were caused not only by careless worker attitudes, but also by inadequate knowledge and ineffective training.

2.5. Benefits of using robotics and construction automation

In the upcoming sections, we will analyse primary advantages that may result from the construction sector embracing robotics and automation. The capability to dramatically alter the traditional construction landscape lies within these state-of-the-art technologies.

2.5.1. Safety improvements

Wang, Zou and Li (2015) suggest that health and safety dangers have been recognised and are widely known within the construction industry. Workers who are at risk of injury while conducting construction on-site activities would benefit from the integration of automation and robotics. Prioritizing the use of robots in hazardous situations is not just a practical measure, it's also an ethical imperative.

The primary objective is to ensure that manual labourers are prevented from working in hazardous conditions such as unsafe heights, remote environments, great depths, and unbearable temperatures (European Construction Sector Observatory, 2021). The erection of tall structures demands the adoption of automated and robotic technologies due to safety hazards as the height of the building rises (Cai, Skibniewski & Bao, 2019).

Outdoor construction activities are highly affected by unfavourable weather conditions, like heavy rain or extreme heat, throughout the year. Galic (2022) argues that deploying automated robots can offer construction sites resilience against exposure to adverse climatic conditions. Robots can also be deployed to carry out repetitive tasks which would otherwise be boring for human workers (Bock, 2015).

In severe cases where the entrance to a construction site is undesirable owing to high contamination levels, the execution of the necessary tasks may be achieved using robots (Skibniewski, 1992). For instance, following the Fukushima nuclear tragedy of 2011, remotely controlled surveying robots called PackBots were deployed as part of the clean-up activities (Kitahara, Nitta & Nishigaki, 2019).

Demolition of buildings is a dangerous undertaking for personnel in the construction industry. The company Brokk responded to the need to separate workers from loud and risky demolition tasks by introducing their first teleoperated robot in 1981 (Melenbrink, Werfel & Menges, 2020). An operator controls the robot remotely from a safe distance away from the demolition. Adami, Doleck and Lucas (2020) claim that demolition robots were used to provide vital assistance in dangerous locations, like the cleanup of Ground Zero post the 9/11 terrorist incidents.

2.5.2. Quality and accuracy improvements

Quality, as identified by Mane and Patil (2015), is among the crucial determinants that directly impact the failure or success of building projects. The continual decrease of quality in the finished products is a significant issue for the construction sector (Kamaruddin, Mohammad & Mahbub, 2015).

Robotics and automation technologies can be deployed to assist quality managers in spotting and managing construction flaws in a timely and precise manner, as opposed to physical inspections administered by human workers (Kim et al. 2015). For example, the alignment of a tunnel boring machine was monitored by Liu et al. (2019) using a robotic total station. The authors demonstrated that using a robotic total station instead of a traditional laser station eliminates issues associated with accuracy and time-consuming calibrations.

2.5.3. Increasing productivity

While productivity has improved continuously in many industries over the previous five decades, it has hardly increased in the building sector (Delgado et al., 2019). Several authors believe that adopting automated technologies and robotics in the construction sector could address some of the productivity shortcomings (Jayaraj & Divakar, 2018, Elattar, 2008, Mahbub, 2012, Bock, 2015).

Morales, Herbzman and Najafi (1999) claim construction robots realise an increase in productivity when working with standardized materials in repetitive tasks. For example, a bricklaying robot called SAM 100 can lay four times the number of bricks than an average human worker can lay (Klinov, 2019). The productivity of human workers may be negatively affected by being tired, feeling worn out or being absent at work (Llale et al., 2020). Hason (1994) suggested that it was possible for automation to improve productivity whilst not being able to necessarily reduce labour requirements.

2.6. Barriers to adoption construction automation and robotics

Chen et al. (2018) allude that despite the widespread acknowledgment of potential advantages that robotics and automation could bring to the construction industry, there are significant obstacles preventing their full integration. With an eye to successfully implement robotics and automation in the construction sector, it is crucial to first grasp the factors which influence their adoption (Talukder, 2012). Conventional construction methods remain dominant in the building sector since they integrate recognizable operating procedures, require basic skills and are empowered by an overall resistance to change (Darlow, James, Rotimi & Shahzad, 2021).

2.6.1. High initial capital investment

Rising equipment costs have led to a lack of automation in the building sector, hence the uptake of this technology in the industry is slow (Akinradewo, Oke & Aigbavboa, 2018). Llale et al. (2019) share the same perspective that adoption of construction robotics and automation is largely hampered by high investment costs involved in acquiring the technology.

Delgado et al. (2019) are of the view that adopting robotics and construction automation is discouraged by prevailing tendering practices that overemphasise awarding contracts to bidders with the lowest prices. The authors claim that this selection criterion forces contractors to reduce profit margins to beat competitors, thus restricting investment in new innovative technologies.

2.6.2. Structure of the construction industry

The foremost impediment to the expansion of automation and robotics in the construction sector is the chaotic and unstructured nature of most construction sites (Melenbrink, Werfel & Menges, 2020). This is unlike the mining sector where adoption of these technologies has been facilitated by the comparatively straightforward nature of mining processes and activities (Dadhich, Bodin & Andersson, 2016).

Balaguer and Abderrahim (2008) noted key elements that render construction sites unstructured in nature. In their observations, processing heavy objects, working with components that have large tolerances, dealing with minimal levels of standardization and prefabrication, and coordinating multiple stakeholders like suppliers and architects are all common aspects of construction sites.

The absence of repetitive tasks in most construction projects renders the use of robots impossible (Hatoum & Nasseredine, 2020). Every building project is distinctive in nature because of varying object dimensions, and that few activities are identically executed at each situation (Folkesson & Lonnroos, 2018). Complicated operations that occur on construction sites need an intelligent on-site robot with the capability to roam and locate itself in the work area (Gharbia et al., 2020).

Delgado et al. (2019) stated that emerging contractors form a huge component of the building sector, they are usually contracted on a temporary arrangement for a specific task in a project. Due to their limited resources, emerging contractors contribute largely to the low implementation rates of construction robotics and automation within the sector.

2.6.3. Potential job losses

Introducing automation and robotics in building sites could result in job cuts, similar to how these technologies have already led to job losses in the manufacturing and automotive industries (Brynjolfsson & McAfee, 2011)

According to PwC (2018) the least educated workers in the construction sector are exposed to losing their jobs to automation by the mid-2030s. Frey and Osborne (2017) are of the same view that unskilled workers in the construction industry are the most vulnerable to job losses. Contrarily, Ruggiero, Salvo and Laurent (2016) lament that people and their skills are not replaced by automation; rather, they are displaced. These displaced workers can occupy new roles that are created as a consequence of adopting robotics and automation in the building sector. As an example, after upskilling, roles of trainers and testers for the robotic systems could be taken up by the low skilled workers.

In countries with rising labour costs or shortages of labour, lowering the requirement for a workforce by automating construction processes becomes extremely beneficial (Galic, 2022).

2.6.4. Complexity of operation and maintenance

Vaha et al. (2013) propose that for construction automation technologies to successfully penetrate the construction market, they must feature user-friendly interfaces. This recommendation aligns with the observations of Li and Liu (2019), who note that the drone utilisation in construction is primarily delayed by a shortage of skilled operators, emphasising the significance of user-friendliness in the broader implementation of such technologies.

Deploying robots on construction sites presents various complexities. Hoeft et al. (2022) show that on-site robots need to understand and adapt to their surroundings. Unlike manufacturing robots that typically work in static, controlled settings, construction robots have to contend with obstacles in large construction areas. Hoeft et al. (2022) propose that this may be realised through communication, where the robots exchange information to co-ordinate tasks and make real-time decisions.

2.7. Theoretical framework

The foundation of this research study will be Everett Rogers' Diffusion of Innovations theory. Rogers initially developed the theory in 1962 and then later optimised it in his 2003 book titled *“Diffusion of Innovations”.* For over four decades, according to Kale and Arditi (2010), various fields such as marketing, manufacturing and economics have shown tremendous interest in understanding the diffusion of innovations.

Wani and Ali (2015) state that the Diffusion of Innovations theory, both in practice as well as in academics, is firmly entrenched and prevails amongst the most used theories for explaining the spread of innovations within societies. Sahin (2006) shares a similar view that the diffusion process of new innovations has been studied thoroughly in the past decades, with Rogers’ DOI theory being the widely favoured model.

The focal point of the theory is to predict how innovations spread in a social system, why the social system members adopt innovations and at what rate does the adoption happen within the system (Dibra, 2015). An innovation, in Rogers’ (2003) terms, is any insight, method, or undertaking which a person views as new. Diffusion is the sequential communication of an innovation through specific avenues among individuals in a societal framework over time (Rogers, 2003).

Per Rogers’ (2003) definition, individuals within a social system, as depicted in Figure 4 below, are classified into five categories according to their inclination to embrace new technologies.

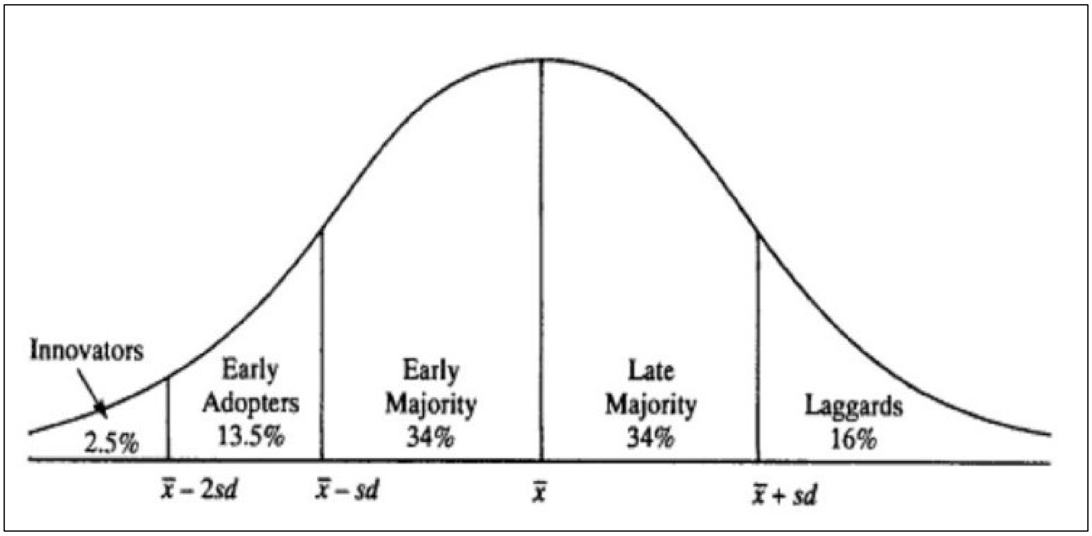

Figure 4 – Adopter categorization (Source: Rogers, 2003)

Rogers (2003) points out that innovators, by taking risks, are willing to be the first to try out new technologies in the face of uncertainty. As soon as the advantages of the innovation begin to appear, the early adopters join in (Robinson, 2009). Kaasinen (2005) said that the early majority of adopters are usually roped into the diffusion process through peer-to-peer conversations where the innovation is already endorsed by early adopters. Late majority and laggards are similar in that they are sceptical and cautious about new ideas until they are pressured by the mainstream into giving in (Rogers, 2003).

Arriving at a conclusion to whether accept or refuse an innovation takes a great deal of time and thinking by potential adopters (Wani & Ali, 2015). Figure 5 below shows the process of innovation-decision as proposed in the DOI theory. This decision-making model, as outlined by Rogers (2003), involves searching and analysing information, where a person is driven to minimise ambiguity about the pros and cons of an innovation.

The model is a sequential journey an individual takes when considering new innovations.

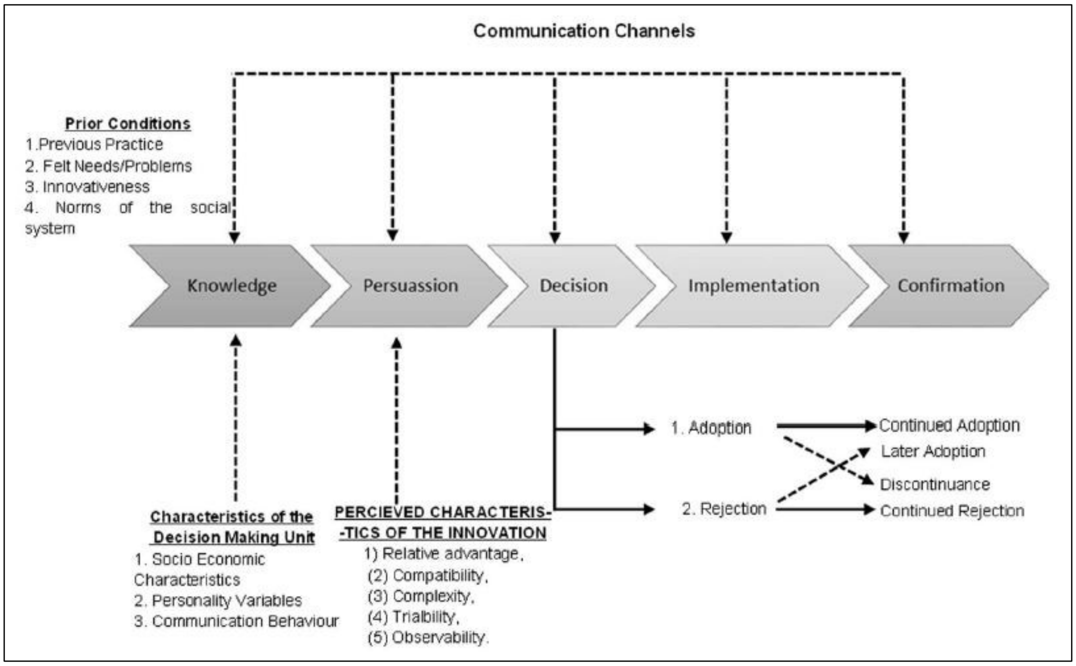

Figure 5 – Five-stage model of the innovation-decision process (Source: Rogers, 2003)

Initially, the individual becomes informed about the innovation and starts to understand how it works. Subsequently, this awareness leads to the development of a negative or positive perception towards the new technology. Following this, the individual embarks on a series of actions culminating in the choice to either accept or refuse the innovation. If the decision is to accept, the individual then starts using the innovation in practice. Finally, the individual seeks confirmation of their choice to persist utilising the innovation. However, the decision is not set in stone - the individual may backtrack on their choice if they encounter new information that contradicts their initial decision.

2.8. Conceptual framework

The conceptual framework, shown in Figure 6 below, has been established for this study. The two primary items that influence the initial awareness level of construction robotics and automation are demographics and external factors. Demographics of the construction professionals, such as age and experience, play a role. For example, a younger professional may be more aware of these technologies due to their familiarity with modern technology trends. External factors, such as socio-economic conditions, shape the environment in which construction professionals operate – impacting their awareness and perceptions.

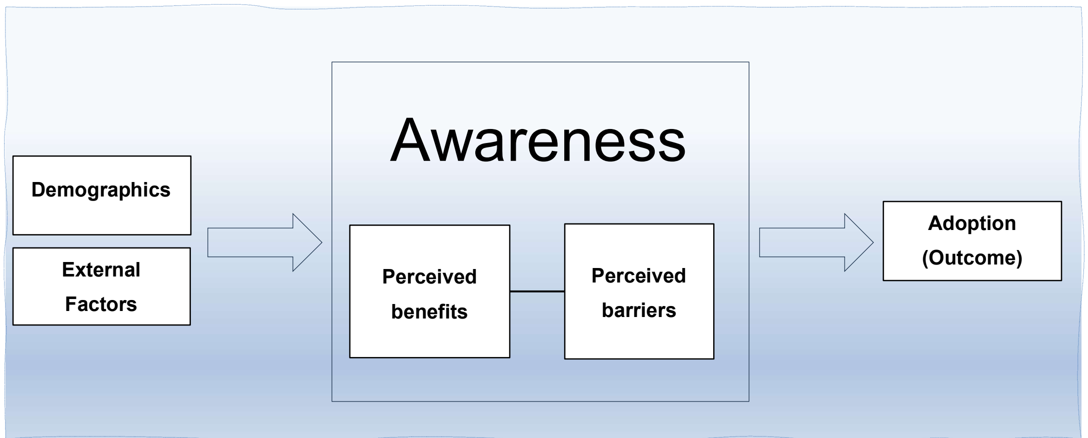

Figure 6 – Conceptual framework for the research

Awareness is the central concept in this model. It represents how much construction professionals are informed about the existence of automation and robotics. Awareness influences both perceived benefits and perceived barriers. If construction professionals are more aware, they may perceive greater benefits such as safety improvements and cost reductions. Similarly, awareness can also affect their perception of barriers to adoption like lack of skills and steep costs.

The outcome represents the actual extent of adoption of robotics and automation by South African construction professionals. This adoption level is influenced by professionals' awareness, their perceived benefits, and their perceived barriers, as well as their demographic characteristics and external factors.

2.9. Summary

This chapter delved into the extensive and intriguing history of robotics and automation in the construction industry. It explored the different types that exist, the benefits they offer, and the reasons for their limited adoption. The chapter concluded by detailing the theoretical and conceptual frameworks that underpin the study. The subsequent chapter addresses the research methodology.

3. CHAPTER 3: RESEARCH METHODOLOGY

3.1. Introduction

Figure 6 below displays the research design, which is centred on the "research onion" framework devised by Saunders, Lewis, and Thornhill (2019). The research onion provides a detailed overview of the major layers that have to be completed to create an effective research methodology (Melnikovas, 2018).

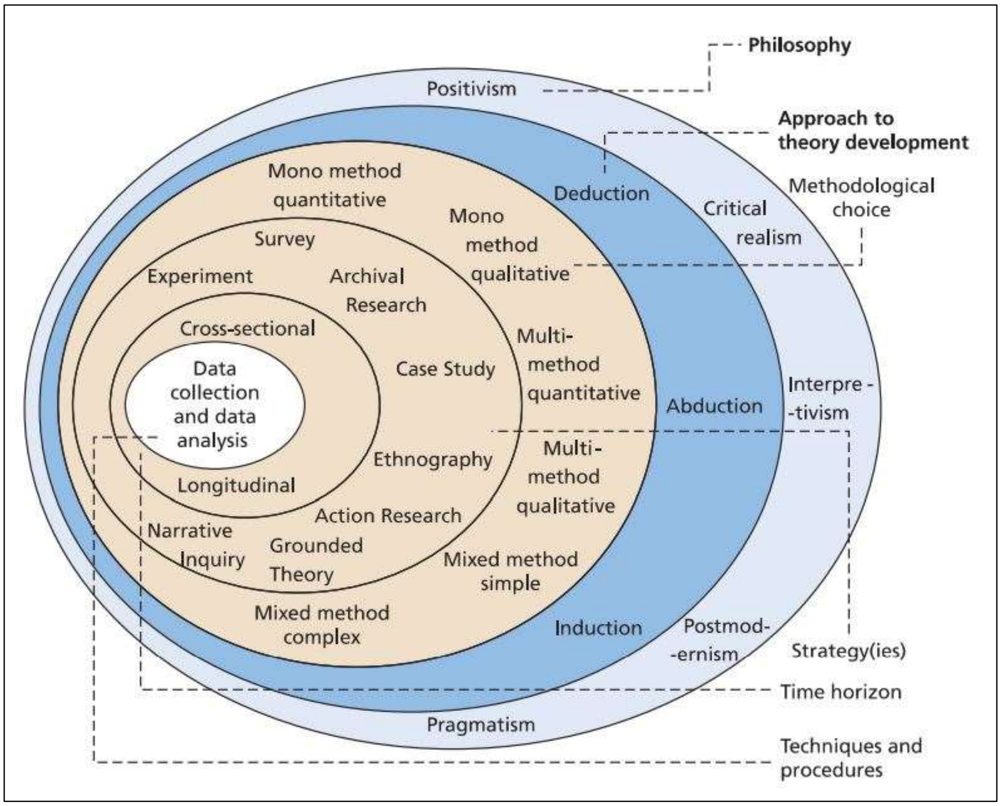

Figure 7 – The 'research onion' model (Source: Saunders, Lewis & Thornhill, 2019)

3.2. Research philosophy

This study adopts a positivist paradigm as its philosophical stance. Positivism involves dealing with an external, independent and observable social reality (Scotland, 2012). Positivist researchers concentrate solely on empirical approaches that provide absolute data and facts free of human interpretation or bias (Saunders, Lewis & Thornhill, 2019). Positivists researchers rely on a singular reality which can be consistently and legitimately assessed using scientific methods (Soiferman, 2010). According to Kivunja and Kuyini (2017) researchers who adopt the positivism paradigm often choose to use quantitative research methods.

3.3. Approach to theory development

For this research study, a deductive approach has been adopted. Melnikovas (2018) claims that deduction begins with an existing theory, followed by the formulation of a question or hypothesis, and the collection of data to validate or refute the hypothesis. The deductive approach perfectly follows the path of logic in that it is a top-down (general to specific) reasoning process (Zalaghi & Khazaei, 2016).

3.4. Methodological choice

This layer of the research onion highlights a fundamental yet critical decision that all researchers must make while designing their research i.e., choosing the study method. The mono-quantitative method was used for data collection and analysis in this study. This means that the study will not utilise a mixture of qualitative and quantitative methods.

3.5. Research strategy

In terms of this study, the quantitative research strategy is suitable for our research context and has been chosen for usage. In quantitative research, the ultimate outcome comprises a set of numerical data that can be subjected to statistical analysis (Sithole, 2016). Beyond critical analysis of numerical data through appropriate statistical methods, the quantitative method also yields reliable results that can be extrapolated to the broader population (Choy, 2014).

3.6. Time horizon

Another critical component in the design of any research endeavour is time horizon. It is located on layer 5 of the ‘research onion’. Time horizon pertains to the duration during which the planned study will be carried out. This research study is cross-sectional in nature. Cross-sectional studies are used to measure variables within a particular moment in time (Mlotshwa, 2019). A cross-sectional time horizon occurs when a researcher studies a specific phenomenon at a certain moment, and the research is a 'snapshot' captured at that time (Saunders, Lewis & Thornhill, 2019). As already mentioned, this research is about assessing construction professionals' awareness of robotics and automation in the South African building sector. Because this is an MBA research component with time constraints, our study does not support a sustained inquiry over a long period.

3.7. Research techniques and procedures

This section occupies the last slice in the research onion and refers to data collection and analysis techniques. According to Rutberg and Bouikidis (2018) researchers who undertake quantitative studies utilise standardised questionnaires to collect numerical data. The same is true for this research, a survey was distributed to construction professionals who were involved in this study. Administering a survey and processing participants' responses requires a relatively short timeframe (Choy, 2014). Another benefit of using a structured survey to collect data is that it is a low-cost method (Mlotshwa, 2019). In our case, a Google Forms online link was emailed to participants so that they fill-in the questionnaire through the internet without the need to meet them physically.

The questionnaire consists of literature-guided questions on construction automation and robotics. The questionnaire was enhanced by adapting the surveys used by Mahbub (2008) and Akinradewo et. al (2020) in their research studies. In summary, the survey was segmented into four parts. Section A, the first part, aimed to gather background data from the participants. Section B focused on questions regarding the participants' awareness of certain robotics and construction automation technologies. Section C explored the respondents' views on the potential benefits of adopting automation technologies. Finally, Section D investigated the participants' perspectives on the barriers to embracing robotic and automation technologies in the field.

3.8. Study population

Kumar (2018) cautions researchers to first define their targeted population before commencing with the study. The research focus guides the researcher in selecting the most suitable study population for addressing the research questions (Symon & Cassell, 2012). The population of interest for this research comprise construction professionals that are based in South Africa.

3.9. Study sample

It would be extremely difficult for a researcher to collect data from an entire study population, a sample should be selected instead (Taherdoost, 2016). The study sample is drawn from the study population. Convenience sampling was adopted for this research. According to Marre (2019) convenience sampling is a non-probabilistic method most suitable in situations where the research subjects are easily available to the researcher. The researcher undertaking this research works in the construction industry and has already established connections with industry professionals. The researcher leveraged his professional network to develop the study sample.

The sample consist of technicians, engineers, architects, contracts managers, project managers, technologists and quantity surveyors. Participants in these professions working on civil engineering projects in Limpopo province were requested to take part in the study. For this type of research, Maree (2019) recommends a sample size with a minimum of 30 respondents. However, the researcher strived to obtain more than 30 research participants to ensure further reliability and validity.

3.10. Data analysis

Microsoft excel was used for analysis of the data. Both inferential and descriptive statistics were employed. In terms of descriptive statistics, standard deviations, frequencies and means were computed. For inferential statistics, the ANOVA test was performed.

3.11. Reliability and validity

According to Masimula (2018) there is an expectation on researchers to produce quality results from their studies. This, in part, can be achieved through the collection of data that is both reliable and valid. Reliability pertains to a study instrument's capability to yield consistent outcomes when employed in the same scenario on numerous occasions, whereas validity refers to the adequacy of a study instrument to measure what it has been designed to measure (Maree, 2019). Heale and Twycross (2015) demonstrated reliability and validity using the alarm clock example. An alarm clock that goes off at 19H00 every night, but has been set for 20H00, is reliable (it always goes off at the same time) however is not valid (ringing during an inaccurate hour).

Validity of the survey instrument has been checked through obtaining inputs from subject matter experts in the field of robotics and automation. Additionally, to check if the survey would be understandable for the participants, a preliminary study was conducted with 10 construction industry professionals. This pilot study aimed to confirm if the questionnaire was clear and made sense to them. The results from this pilot study suggested that the questionnaire was well-prepared and understandable for the general respondents.

A Cronbach's alpha coefficient test was applied to assess the data's reliability and appropriateness for the study. As outlined by Maree and Pietersen (2016), the interpretation of Cronbach's alpha values follows a general standard: values of 0.90 are highly reliable, 0.80 reflect moderate reliability, and 0.70 indicates a somewhat lower level of reliability. For section B, C and D, the coefficients were 0.91, 0.83 and 0.77 respectively.

3.12. Ethical considerations

Securing ethical clearance from the University of the Witwatersrand was the initial step before commencing the research. In general, ethical matters like participant consent, transparency, privacy, respect and honesty were be maintained at all times during the engagement of participants. The student also made sure that the safety of research respondents was protected and guaranteed. The ethical clearance certificate is attached as part of the appendices.

3.13. Summary

This chapter mainly concentrated on the research methodology that was followed by this study. The study was designed based on the “research onion” model. This model adopts a funnel approach to research design, starting at the philosophical view down to the intricacies of how the data was actually collected. The next chapter will present the findings of the research.

4. CHAPTER 4: FINDINGS

4.1. Introduction

The method employed for data collection was presented in the previous section. The current section concentrates mainly on the presentation and analysis of the collected data. An online survey was distributed via an online Google Forms link to a targeted group of 50 participants employed in the building sector within Limpopo province. Ultimately, valid feedback was received from 44 participants, indicating a remarkable participation rate of 88%.

4.2. Demographics

In Section A of the survey, the objective was to collect background details of the research participants, which encompassed elements such as gender, age, educational qualifications, professional designation, experience level in the building sector, and employer details. Figure 8 shows the age distribution among the participants, with females comprising 22% and males constituting 78% of the total respondents.

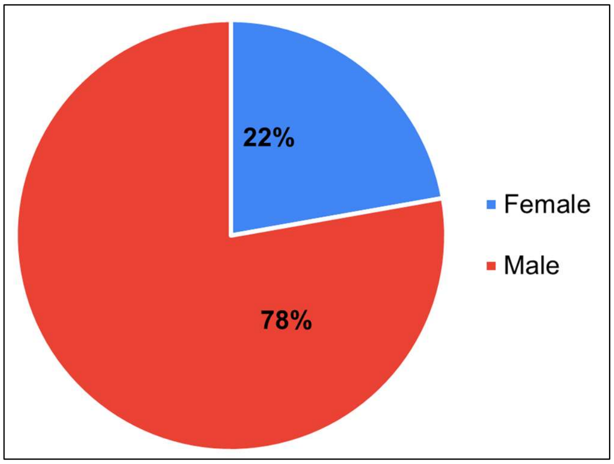

Figure 8 - Gender of participants

The age composition of the participants is illustrated in Figure 9 below, which presents their age grouped into four sets: over 55 years, 46 to 55 years, 36 to 45 years and 25 to 35 years. The largest segment of the respondents falls within the 25 to 35 years category, constituting 53% of the total. The 36 to 45 years category follows with a contribution of 31%. The remaining age groups, 46 to 55 years and over 55 years, accounted for the lowest percentages, with 13% and 2% respectively.

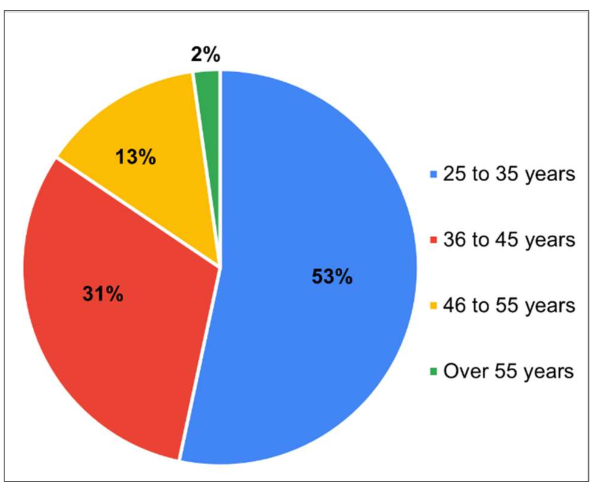

Figure 9 – Age of participants

Regarding the educational qualifications of the research participants, the majority, accounting for 40%, held a university degree, which was the highest among the group. Following that, 24% of the respondents possessed an honours degree.

Conversely, 18% of the participants had a diploma, representing the lower end of the spectrum. Similarly, 18% of the respondents achieved a master's degree. Figure 10 below provides a summary of this information.

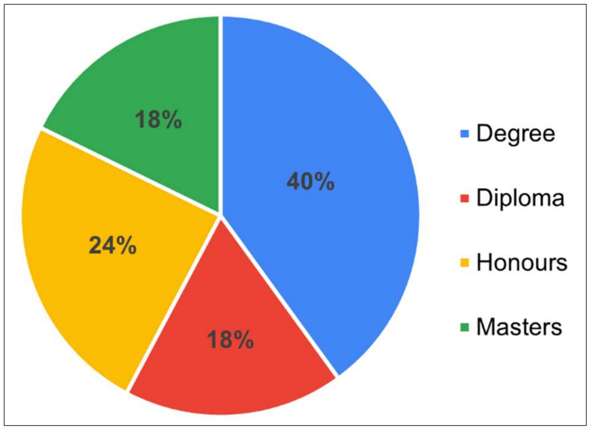

Figure 10 – Educational qualifications

Within the South African building sector, professionals fulfil a variety of roles related to their specific tasks. These roles encompass, amongst others, designing infrastructure within consulting environments, constructing structures as contractors, and supervising project operations. Figure 11 below depicts the distribution of participants' professional designations as observed in the research.
In this particular study, civil engineering technologists constituted the largest portion of respondents at 33%, while civil engineers accounted for 29% of the participants. Project managers represented 18% of the respondents, whereas both contract managers and architects had an equal share of 7% each. Technicians and quantity surveyors formed the smaller percentages, comprising 4% and 2% respectively.

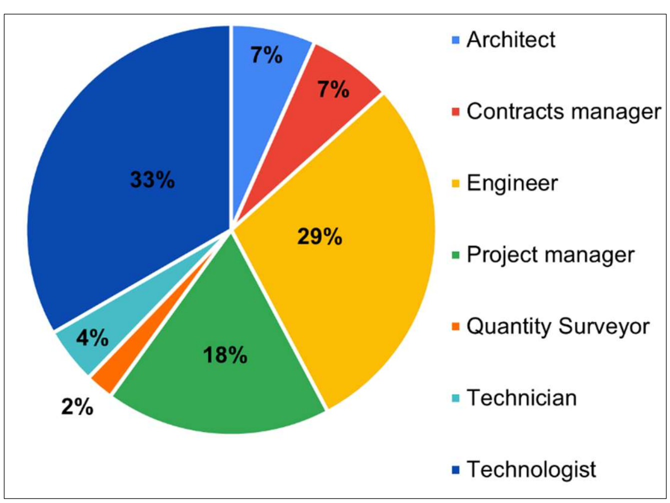

Figure 11 – Professional designations of respondents

Displayed in Figure 12 below, participants with a professional experience ranging from 1 to 5 years accounted for 11% of the total. The majority of respondents, comprising 33%, possessed 6 to 10 years of experience within the construction sector. Those with 11 to 15 years of experience denoted 22% of the respondents. Only a small proportion, 9% of the participants, reported having 16 to 20 years of experience. Lastly, the most seasoned individuals with 20 years and above of experience contributed 24% to the research sample.

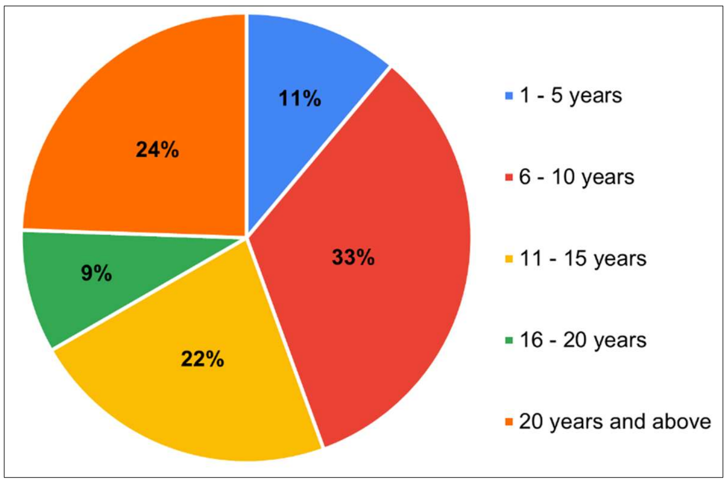

Figure 12 – Respondents' level of experience

The study sample covers a varied array of employers within the construction sector in Limpopo province. According to the information depicted in Figure 13, the bulk of research respondents, accounting for 64%, are consultants. Government employees make up 24% of the study sample. Private clients represent 7% of the participants, while contractors constitute the smallest portion at 4%.

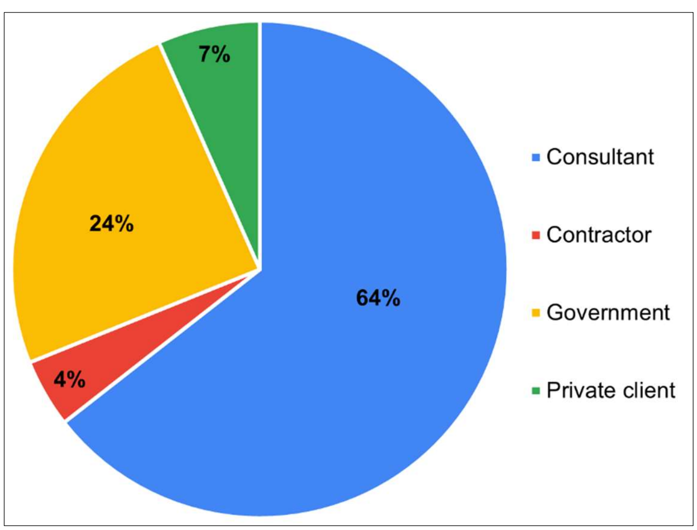

Figure 13 – Employers of the research participants

4.3. Awareness

In addressing the first research question, *"What is the level of awareness of the existing types of robotics and construction automation currently in use in the construction industry?"*, participants in the research were requested to indicate their familiarity with 10 specific robotics and construction automation technologies. These evaluations utilised a Likert scale, where a score of 1 signified "Very low" awareness, 3 denoted "Average" awareness, and 5 corresponded to "Very high" awareness.

4.3.1. Sensing technologies

The table presented below summarizes the responses of construction professionals regarding their level of awareness of sensing technologies. Among the participants, 24% specified that they possess a "very high" level of awareness, 36% stated their awareness as "high," and 27% rated it as "average." A smaller portion of respondents, 9% and 4%, reported their awareness as "low" and "very low," respectively.

Sensing technologies	Frequency	Percentage
Very high	11	25%
High	15	34%
Average	12	27%
Low	4	9%
Very low	2	5%
Total	44	100%

Table 1 – level of awareness of sensing technologies

4.3.2. 3D printing

Concerning the awareness level of construction professionals regarding 3D printing technologies, an even distribution of 20% was observed for "very high," "high," and "low" awareness levels. In contrast, 36% of construction professionals rated their awareness as "average," while a minimal fraction (2%) indicated "very low" awareness. The results are concisely condensed in Table 2 underneath.

3D printing	Frequency	Percentage
Very high	9	20%
High	9	20%
Average	16	36%
Low	9	20%
Very low	1	2%
Total	44	100%

Table 2 – level of awareness of 3D printing

4.3.3. Virtual reality

Pertaining to virtual reality awareness, 8% of participants reported a "very high" level, while an equivalent 8% indicated a "high" level of awareness. The majority, 32%, perceived their awareness to be "average". Following closely, 25% of respondents classified their awareness as "low". A mere 3% of construction professionals indicated that they had a "very low" awareness. See Table 3 for detailed reference.

Virtual reality	Frequency	Percentage
Very high	8	18%
High	8	18%
Average	14	32%
Low	11	25%
Very low	3	7%
Total	44	100%

Table 3 – level of awareness of virtual reality

4.3.4. Autonomous vehicles

Table 4 illustrates the participants' understanding of autonomous vehicles within the construction sector. Most of them, at 32%, were only slightly familiar, indicating a "low" awareness. 27% of the construction professionals described their knowledge as "high." Meanwhile, 14% felt they had an extensive ("very high") understanding, and 18% believed they had a moderate ("average") awareness. Only 4% admitted to having very little ("very low") knowledge about these vehicles.

Autonomous vehicles	Frequency	Percentage
Very high	6	14%
High	12	27%
Average	8	18%
Low	14	32%
Very low	4	9%
Total	44	100%

Table 4 – level of awareness of autonomous vehicles

4.3.5. Drones

In response to questions related to their level of awareness concerning drones, a notable 23% of respondents characterized their awareness as “very high” - indicating a comprehensive understanding of drones. Additionally, 32% rated their awareness as “high”. Another 30% of participants regarded their awareness as “average,” suggesting a moderate level of knowledge in this regard. Towards the lower side of the awareness scale, only 14% of the research participants indicated a “low” level of awareness. An even smaller percentage, specifically 2%, expressed a “very low” level of awareness, signifying minimal familiarity with the subject.

Drones	Frequency	Percentage
Very high	10	23%
High	14	32%
Average	13	30%
Low	6	14%
Very low	1	2%
Total	44	100%

Table 5 – level of awareness of drones

4.3.6. Robotic arms

The survey included questions about robotic arms as a category of automation and robotics technologies. From the 44 construction professionals who participated in the survey, 2 of them (5%) specified that they possess a "very high" awareness level when it comes to robotic arms. Additionally, 8 participants (18%) reported having a "high" awareness of robotic arms, while 9 individuals (20%) indicated an "average" level of awareness.

Interestingly, the largest group of participants, totalling 17 individuals (39%), revealed that they possessed a limited understanding of robotic arms and rated their awareness as "low." Lastly, 8 participants (18%) acknowledged having a "very low" level of awareness about robotic arms.

Robotic arms	Frequency	Percentage
Very high	2	5%
High	8	18%
Average	9	20%
Low	17	39%
Very low	8	18%
Total	44	100%

Table 6 – level of awareness of robotic arms

4.3.7. Building Information Modelling (BIM)

Table 7 presents feedback conveyed by respondents in the research study concerning their awareness of Building Information Modelling (BIM). The majority of respondents (30%) reported having an "average" level of awareness regarding BIM. An equal distribution of 25% was observed for those who indicated their awareness level as "very high" and "low," respectively. A smaller proportion of construction professionals, specifically 18%, characterized their awareness as "high." Notably, one research participant, constituting 2% of the study sample, indicated having a "very low" level of awareness.

Building Information Modelling	Frequency	Percentage
Very high	11	25%
High	8	18%
Average	13	30%
Low	11	25%
Very low	1	2%
Total	44	100%

Table 7 – level of awareness of Building Information Modelling

4.3.8. Computer-Aided Design (CAD)

Among the research participants, 52% reported having a "very high" level of awareness regarding CAD. Additionally, 25% of respondents expressed a "high" level of awareness, as indicated by 11 research participants. Approximately 14% of participants assigned an "average" rating to their CAD awareness, while 9% stated a "low" level of awareness. Remarkably, there were no responses indicating a "very low" level of awareness. Detailed results are provided in Table 8 beneath.

Computer-Aided Design	Frequency	Percentage
Very high	23	52%
High	11	25%
Average	6	14%
Low	4	9%
Very low	0	0%
Total	44	100%

Table 8 – level of awareness of Computer-Aided Design

4.3.9. Global Positioning System (GPS)

Table 9 presents an overview of awareness levels pertaining to GPS among the research respondents. The distribution of awareness levels is as follows: 50% reported a "very high" awareness level, 23% indicated "high" awareness, 20% described their awareness as "average," 5% noted a "low" awareness level, and 2% specified a "very low" awareness level.

Global Positioning System	Frequency	Percentage
Very high	22	50%
High	10	23%
Average	9	20%
Low	2	5%
Very low	1	2%
Total	44	100%

Table 9 – level of awareness of Global Positioning System

4.3.10. Prefabrication (Off-Site Construction)

In the research questionnaire, construction professionals were asked about their familiarity with prefabrication, also known as off-site construction. Of those who responded, 36% claimed to have a "very high" understanding of the topic. Not far behind, 34% felt they had a "high" level of familiarity. Meanwhile, 23% believed their knowledge was "average". A smaller percentage felt less informed, with 2% indicating "low" awareness and 5% admitting to a "very low" understanding.

Prefabrication / Off-site Construction	Frequency	Percentage
Very high	16	36%
High	15	34%
Average	10	23%
Low	1	2%
Very low	2	5%
Total	44	100%

Table 10 – level of awareness of prefabrication (off-site construction)

4.3.11. Overall level of awareness

Figure 14 underneath shows the overall awareness levels of all research participants regarding the various types of automation and robotics used in the construction sector. Survey respondents were questioned about their awareness levels regarding various types of construction automation and robotics on a range from 1 to 5, where 1 signified very low awareness, whereas 5 indicated very high awareness.

Among the construction professionals surveyed, computer-aided design (CAD) emerged as the most recognized form of construction automation and robotics.

Following closely, the second-highest level of awareness was associated with the Global Positioning System (GPS). In contrast, robotic arms earned the least level of recognition among the research participants.

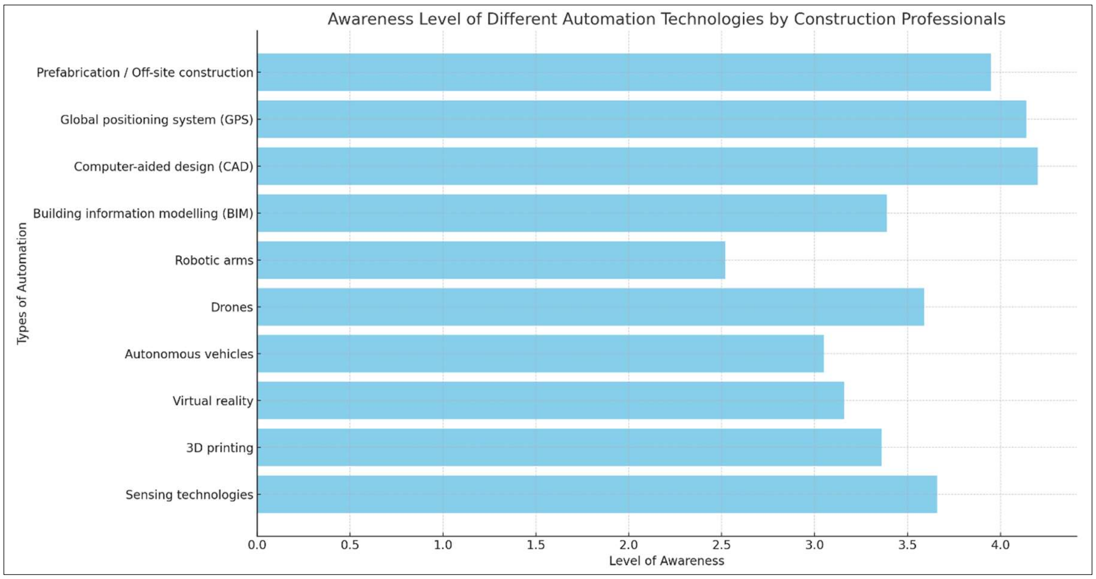

Figure 14 – Overall level of awareness of types of automation and robotics

4.3.12. Effect of demographics on awareness

As per the conceptual model designed for this research, it has been suggested that demographics may affect the awareness of robotics and construction automation technologies by construction professionals. The demographical details of the research participants have already been presented in this chapter, they include gender, age, educational qualifications, job title, work experience and type of employer. Table 11 below outlines the mean scores for each demographic category on the awareness of robotic and construction automation technologies.

To assess whether demographics affect awareness, One-Way ANOVA tests have been performed on each of the six (6) categories separately. The F-Statistic is another name for the widely used ANOVA test (Wegner, 2012). Each demographical category (single factor) is an independent variable, with awareness level being the dependent variable. The F-Statistic test, in terms of its purpose, is to determine whether variables are statistically dependent by comparing their means (Wegner, 2012). In simple words, that is to say for example, is awareness of a particular type of robotic technology dependent on age or gender.

The statistical tests were conducted using a confidence level of 95% and significance (p-value) of 0.05. In the analysis, a p-value below 0.05 suggests the presence of a statistically significant difference. This implies that the observed mean differences would not have occurred by chance. On the other hand, p-values bigger than 0.05 suggest the absence of any meaningful difference between the groups or variables being compared. It is important to note that the calculated F-Statistic and F-Critical values for all the demographic categories as shown in Table 12.

Demographic		Sensing technologies	3D printing	Virtual reality	Autonomous vehicles	Drones	Robotic arms	BIM	CAD	GPS	Off-site
Gender	Male	3,6	3,4	3,1	3,1	3,5	2,5	3,3	4,3	4,3	4,1
	Female	3,8	3,4	3,2	3,0	3,8	2,6	3,6	3,8	3,7	3,6
Age	25 to 35 years	3,6	3,3	3,2	3,0	3,7	2,5	3,4	3,9	3,9	3,8
	36 to 45 years	3,6	3,4	3,1	3,1	3,5	2,6	3,1	4,5	4,4	4,1
	46 to 55 years	4,0	3,7	3,0	3,2	3,5	2,2	4,0	4,7	4,3	3,8
	Over 55 years	4,0	3,0	3,0	4,0	4,0	4,0	4,0	4,0	5,0	5,0
Qualification	Diploma	3,9	3,5	3,1	3,0	3,6	3,1	3,4	4,1	4,3	3,9
	Degree	3,5	2,9	3,1	2,7	3,2	2,2	2,9	4,0	4,0	3,9
	Honours	3,8	3,7	2,9	3,7	4,0	2,5	4,0	4,4	4,3	4,0
	Masters	3,6	3,9	3,8	3,1	3,9	2,8	3,8	4,5	4,1	4,0
	Architect	3,0	2,7	2,7	3,3	2,7	3,0	3,3	5,0	3,0	3,3
Job Title	Contracts Manager	4,0	3,7	4,0	3,0	4,0	3,0	3,7	4,3	4,0	4,3
	Engineer	3,5	3,3	3,2	3,5	3,9	2,5	3,8	4,3	4,4	4,2
	Project Manager	4,1	3,9	3,1	3,0	3,9	2,8	3,5	4,4	4,0	3,8
	Quantity Surveyor	4,0	2,0	3,0	3,0	3,0	2,0	3,0	2,0	4,0	4,0
	Technician	3,5	2,5	2,5	2,0	3,5	3,0	2,0	3,5	4,0	4,0
	Technologist	3,6	3,4	3,1	2,7	3,3	2,1	3,1	4,1	4,3	3,9
Experience	0 - 5 years	3,8	3,0	2,6	3,0	3,4	2,0	4,0	3,2	4,0	3,8
	6 - 10 years	3,6	3,5	3,6	3,1	3,7	2,9	3,2	4,2	3,9	3,8
	11-15 years	3,8	3,2	3,1	2,7	3,7	2,2	3,3	4,0	4,2	4,2
	16 - 20 years	4,3	4,0	4,0	4,0	4,3	3,8	3,0	5,0	5,0	4,8
	Over 20 years	3,5	3,3	2,7	3,0	3,3	2,2	3,6	4,6	4,3	3,8
Employer Type	Consultant	3,8	3,2	3,2	3,1	3,5	2,4	3,4	4,2	4,2	4,1
	Contractor	1,5	3,0	2,0	2,0	3,0	2,0	1,5	2,5	1,5	2,0
	Government	3,9	3,9	3,5	3,0	4,1	2,9	3,5	4,3	4,5	4,1
	Private Client	3,3	3,0	2,3	3,7	3,3	3,0	3,7	5,0	3,7	3,7

Table 11 – Consideration of participant's demographics on level of awareness

Table 11 above shows the mean scores of participants grouped according to the six biographical groupings as per the research survey. The data was arranged from the raw data obtained from responses of participants. The 10 types of robotics and automation technologies have each been assigned a mean level of awareness across the six biographical groupings. This table in itself present a clearer picture of how each biographical group rated its awareness on the survey.

	p-value	**F-Statistic**	**F-Critical**
Gender	0,7638	0,0931	4,4139
Age	0,2081	1,5925	2,8663
Qualification	0,0960	2,1036	2,5787
Job Title	**0,0277**	2,7480	2,3861
Experience	**0,0170**	3,3714	2,5787
Employer Type	**0,0000**	15,999	2,8663

Table 12 – calculated values of p-value, F-Statisitc and F-Critical

From Table12 above it can be seen that the demographical categories of job title, work experience and type of employer have p-values of less than 0.05. Also, their F-Stastic values are all greater than their corresponding F-Critical values. This finding presents certain inferences. The meaning and implications of these findings will be discussed in the following chapter.

4.4. Benefits

This section of the study deals with the second research question: *"What are the perceived benefits of adopting the use of robots and automation in the South African construction industry?"* This question aimed at gathering opinions of construction professionals concerning the extent of possible benefits attainable through implementing automation and robotics within the building sector in South Africa. To assess the extents, a list of potential benefits was constructed thorough an appraisal of prior research and included in the research questionnaire. Participants were subsequently asked to rate these benefits on a Likert scale, which scaled from 1 (indicating a 'very low' extent) to 5 (indicating a 'very high' extent)."

4.4.1. Occupational safety improvements

Below, Table 11 presents the insights gathered from research participants concerning their perceptions of the impact of construction automation and robotics on occupational safety. Among the 44 participants who participated in the study, 9% expressed a strong belief ("very high") in the substantial benefits of automation and robotics, while 57% regarded these benefits as "high." Additionally, 18% of participants characterized the impact as "average" in terms of occupational safety improvements. At the other extreme of the scale, 14% of construction professionals assessed the benefits as "low," and 2% deemed them "very low."

Occupational safety improvements	Frequency	Percentage
Very high	4	9%
High	25	57%
Average	8	18%
Low	6	14%
Very low	1	2%
Total	44	100%

Table 13 – extent of occupational safety improvements

4.4.2. Higher quality and accuracy

When asked about how much construction automation and robotics enhance the accuracy and quality of construction projects, 20% of construction professionals said the improvement was 'high', while 16% rated it as 'very high'. Only 8% of the respondents believed that the benefit in quality and accuracy was 'average'. Worthy to note is that none of the 44 respondents chose 'low' or 'very low' as their ratings.

This information is shown in Table 12 below.

Higher quality and accuracy	Frequency	Percentage
Very high	16	36%
High	20	45%
Average	8	18%
Low	0	0%
Very low	0	0%
Total	44	100%

Table 14 – extent of higher quality and accuracy

4.4.3. Increased productivity

Participants were questioned regarding their perspectives on the extent to which robotics and automation offer increased productivity benefits to the construction industry. Their feedback is presented in Table 13 below, where 39% expressed a 'very high' belief in the substantial benefits of robotics for increased productivity, while 50% regarded it as 'high'. Additionally, 9% viewed it as 'average', 2% considered it to have a 'low' impact, and none of the participants endorsed the notion that robotics and automation offered 'very low' productivity enhancements for the construction sector.

Increased productivity	Frequency	Percentage
Very high	17	39%
High	22	50%
Average	4	9%
Low	1	2%
Very low	0	0%
Total	44	100%

Table 15 – extent of increased productivity

4.4.4. Reduced material disposal

The application of robotics and construction automation in the building sector offers a myriad of benefits, as noted in this study's literature review section. One of those benefits is the generation of reduced waste material from construction sites. Survey respondents were requested to express their views on how effectively these technologies contribute to this benefit. A 'Very high" rating was given by 30% of the research participants whilst 48% of the participants indicated that they believed that the benefit was ‘High’. None of the participants was of the view that the benefit of reduced material disposal was ‘Very low’. A minimal 2% of participants rated the item as ‘Low’, whilst 20% rated it as ‘Average’. Detailed information regarding these responses is systematically presented in Table 16, which summarises the questionnaire results for this particular question.

Reduced material disposal	Frequency	Percentage
Very high	13	30%
High	21	48%
Average	9	20%
Low	1	2%
Very low	0	0%
Total	44	100%

Table 16 – extent of reduced material disposal

4.4.5. Cost reduction

Regarding this part of the study, the exact question posed to research participants on the survey was “*To what extent do robotics and construction automation yield the following benefits for the construction industry? Cost reduction*”. This question was designed to gauge the perceived benefits of these technologies in terms of reducing costs within the construction industry. Again, participants’ responses were quantified using a Likert scale which scaled from 1 to 5. This scale was calibrated with '1' signifying a perception of 'Very low' benefit and '5' signifying a 'Very high' benefit.

The largest group, comprising 36% of the respondents, rated the cost reduction benefits as 'Average', suggesting a moderate impact. Meanwhile, a substantial 25% of participants perceived these benefits as 'Very high', indicating a strong positive impact. Close to this, 23% of the respondents viewed the benefits as 'High', while a smaller segment, 14%, rated them as 'Low'. Only a small percentage of 2% thought the benefits were “Very low’. The detailed summarised findings are presented in Tabel 17 below.

Cost reduction	Frequency	Percentage
Very high	11	25%
High	10	23%
Average	16	36%
Low	6	14%
Very low	1	2%
Total	44	100%

Table 17 – extent of cost reduction

4.4.6. Time saving

Generally, as human beings exist on planet earth, time saving is about using one’s time more efficiently in order to free up time to carry out other activities. This is basic common sense – optimising so that less time is used in running daily errands and so on. Within the context of this research, it was asked of participants to indicate their views on how well robotics and construction automation assisted construction projects to save time. In their responses, 41% and 43% of construction professionals involved in the study rated time saving as ‘Very high’ and ‘High’, respectively. Remarkably, as shown in Table 18, there was no participant who thought that robotics and construction automation yielded ‘Low’ or ‘Very low’ benefits in relation to time saving. An ‘Average’ rating was given by 7% of the respondents.

Time saving	Frequency	Percentage
Very high	18	41%
High	19	43%
Average	7	16%
Low	0	0%
Very low	0	0%
Total	44	100%

Table 18 – extent on time saving

4.4.7. Less human labour

The survey also centred around evaluating the perceived influence of robotics and construction automation on labour utilisation within the construction sector. The construction professionals were requested to gauge the extent to which they believed automation contributed to utilisation of less labour - a thorny subject in the South African context. The responses highlighted a broadly positive view of these technologies in reducing labour needs.

A noteworthy 45% of the respondents rated the impact as 'Very high' showing a strong conviction in the ability of robotics and automation substantially reducing labour requirements. Following this, 27% of the professionals perceived the impact as 'High', aligning with the view that these technologies do contribute to labour reduction, although to a lesser degree than the 'Very high' category. Meanwhile, a quarter of the participants, at 25%, considered the impact to be 'Average', suggesting a moderate effect on labour utilisation. 2% of the respondents viewed the impact as 'Low', indicating a less pronounced effect as outlined in Table 19 below.

Less human labour	Frequency	Percentage
Very high	20	45%
High	12	27%
Average	11	25%
Low	1	2%
Very low	0	0%
Total	44	100%

Table 19 – extent on less human labour

4.4.8 Overall extent of benefits

The bar chart in Figure 15 below provides a visual overall representation of the perceived benefits of robotics and construction automation within the construction industry, as rated by a sample of industry professionals on a Likert scale where 1 indicates a 'very low' benefit and 5 indicates a 'very high' benefit. The horizontal bars, shaded in a calming light blue, correspond to different benefits, with the length of each bar representing the mean score assigned by the respondents.

At the top, 'Increased productivity' and 'Time saving' are both rated as the most significant benefits with a mean score of 4.3, illustrating a solid consensus on their importance. Closely following are 'Higher quality and accuracy' and 'Less human labour', each with a mean score of 4.2, suggesting that these areas also receive considerable improvements through the adoption of automation technologies. 'Reduced material disposal' is rated slightly lower at 4, yet still indicates a high level of benefit. 'Occupational safety improvements' are acknowledged with a respectable score of 3.6, while 'Cost reduction' receives the lowest score of 3.5, which might reflect a more nuanced view on the economic impact of these technologies. The descending order of the bars effectively conveys the hierarchy of benefits as perceived by construction professionals, allowing for an at-a-glance assessment of the most and least impactful areas of robotics and automation in construction.

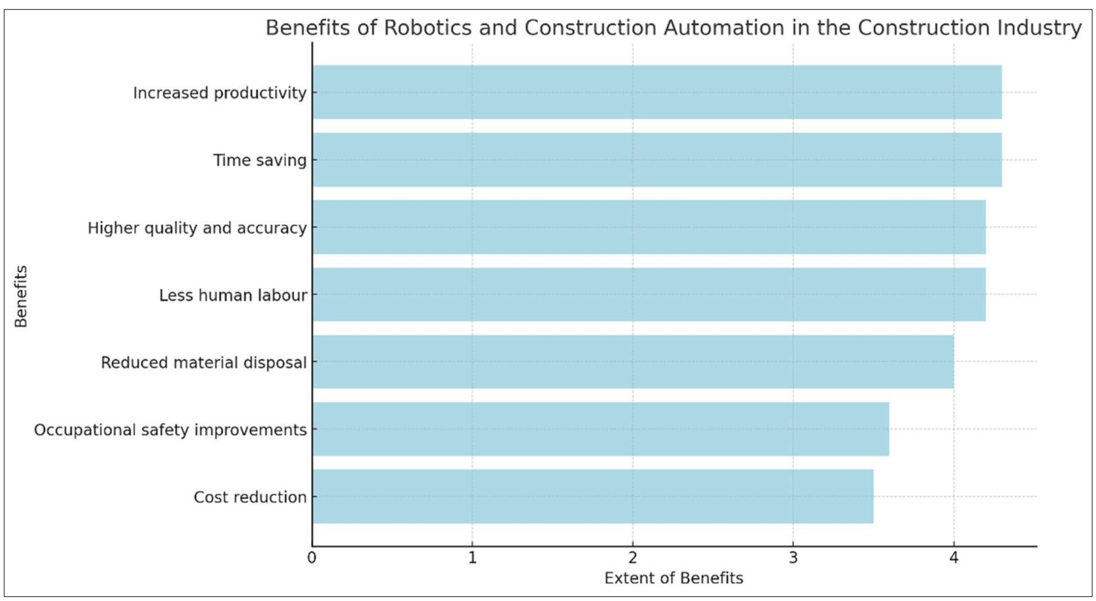

Figure 15 – benefits of robotics and construction automation in the construction sector

4.5. Barriers

This section is mainly concerned with the third and last research question of this study, which is *“What are the perceived barriers to adoption of robotics and automation in the South African construction industry?”* This question is designed to elicit insights into the specific barriers or obstacles that construction professionals in South Africa believe exist when contemplating the acceptance of robotics and automation technologies into the building sector. It seeks to identify the subjective views and experiences these professionals have.

By asking about 'perceived' barriers, the question acknowledges that the responses may be based on personal opinions and industry observations. Ultimately, a thorough review of the literature revealed 9 potential barriers, these were included in the study questionnaire that was emailed to participants. For each of the identified barriers, respondents used a Likert scale of 1 to 5, where ‘1’ denotes ‘Strongly disagree’ and ‘5’ implies ‘Strongly agree’, to indicate their views regarding the extent to which each item acted as a deterrent to implementation of robotics and construction automation in the building sector.

4.5.1 High costs of acquiring technologies.

Table 20 below reflects the sentiments of our 44 sampled construction professionals in relation to the extent which high acquisition costs constitute a barrier to adopting robotics and construction automation technologies in the building industry. As is evident, 57% of the participants 'Strongly agree' that high costs present a significant hindrance - highlighting the concern that the initial capital required for these technologies is a massive barrier. Adding to this, 39% also 'Agree', reinforcing the perception that cost is a deterrent.

5% of respondents remain 'Neutral', suggesting that they may see the costs as justifiable or are uncertain about the impact of cost as a barrier. Lastly, none of the respondents 'Disagree' or 'Strongly disagree', indicating a consensus in recognizing cost as a serious challenge to adoption.

High costs of acquiring technologies	Frequency	Percentage
Strongly agree	25	57%
Agree	17	39%
Neutral	2	5%
Disagree	0	0%
Strongly disagree	0	0%
Total	44	100%

Table 20 – extent of high costs of acquiring technologies.

4.5.2 Unavailable locally

The second barrier identified from relevant publications and incorporated in the research questionnaire was the unavailability of robotics and construction automation locally. In terms of Table 21, agreement amongst the respondents is strikingly clear on this barrier. Not a single respondent fell into the 'Disagree' or 'Strongly disagree' categories. On the other hand, 16% maintained a ‘Neutral’ position, indicating a balanced view on the matter. Moving up the scale of agreement, 34% are of the view that the local unavailability of the technologies is a significant barrier. Most notably, the majority of respondents at 50% firmly chose 'Strongly agree', affirming that scarcity impedes adoption.

Unavailable locally	Frequency	Percentage
Strongly agree	22	50%
Agree	15	34%
Neutral	7	16%
Disagree	0	0%
Strongly disagree	0	0%
Total	44	100%

Table 21 – extent of unavailability locally

4.5.3 Difficult to use and not easily understood.

It is understood that robotics and construction automation are modern and technically complex technologies, thus rendering them difficult to understand or operate. This complexity suggests that operators could need specialised training before they can effectively utilise these technologies on construction sites. Against this backdrop, the study queried participants on whether they perceived this complexity as an obstacle to the adoption of robotics and construction automation in the building sector. Table 22 below presents their responses, with 11% and 43% of respondents agreeing that the difficulty of use indeed poses a barrier, whist 32% maintained a 'Neutral' position. 9% and 5% of the participants respectively 'Disagree' and 'Strongly disagree' with this viewpoint.

Difficult to use	Frequency	Percentage
Strongly agree	5	11%
Agree	19	43%
Neutral	14	32%
Disagree	4	9%
Strongly disagree	2	5%
Total	44	100%

Table 22 – extent of difficulty in usage

4.5.4 Incompatible with current construction practices

When examining the existing condition of the building sector in South Africa, some of the methods currently applied to build structures may not be compatible or work well with the use of robots and automated technology. This mismatch could make it difficult for the construction industry to start using these new technologies. Construction professionals were asked to share their thoughts on how much of a problem this could be. 14% and 30% agree with this notion, whilst 30% disagreed. 27% of participants chose a middle ground, providing a 'Neutral' rating. The data is listed in Table 23 beneath.

Incompatible with current construction practices	Frequency	Percentage
Strongly agree	6	14%
Agree	13	30%
Neutral	12	27%
Disagree	13	30%
Strongly disagree	0	0%
Total	44	100%

Table 23 – extent of incompatibility with current construction practices

4.5.5 Maintenance costs

There is a cost to keeping machines running and in good condition. These costs for repairs and upkeep may make it unaffordable for companies to use this kind of technology. This raises an important question: Could the cost associated with the maintenance of robotics and construction automation be a hindrance to their wider adoption in the building sector? When this query was posed to research participants, 25% and 39%, affirmed that indeed, the maintenance costs could act as a barrier to embracing these advanced technologies.

In opposition to that, 7% and 2% of respondents disagree with the idea that maintenance costs could be a barrier to adoption. Table 24 shows detailed responses of participants.

Maintenance costs	Frequency	Percentage
Strongly agree	11	25%
Agree	17	39%
Neutral	12	27%
Disagree	3	7%
Strongly disagree	1	2%
Total	44	100%

Table 24 – extent of maintenance costs

4.5.6 Low awareness of the technologies

There is an argument based on a logical premise: awareness is the first step towards adoption. This simply means that adoption may not happen for as long as the building sector is unaware of the existence of robotics and construction automation. One of the survey questions meant to probe this exactly. In a show of overwhelming majority at 43%, research participants ‘Strongly agree’ that low awareness could pose as a barrier. Following closely, 34% also ‘Agree’ that lack of awareness might impede the adoption process.

The rest of the responses are outlined in Table 25 below.

Low awareness of the technologies	Frequency	Percentage
Strongly agree	19	43%
Agree	15	34%
Neutral	7	16%
Disagree	2	5%
Strongly disagree	1	2%
Total	44	100%

Table 25 – extent of low awareness of the technologies

4.5.7 Resistance to change by the construction industry.

This barrier is concerned with instances where role players in the construction industry refuse to accept or adapt to new methods – thereby sticking with what they know and are used to. The adoption of automation and robotics may face opposition from the building industry. The data (Table 26) gathered from 44 construction professionals sheds light on this issue. Collectively, 66% of the respondents agree that resistance to change is an impediment to implementation. Taking a divergent view, 9% of respondents do not consider resistance to change as a significant barrier to adoption.

Resistance to change by the construction industry	Frequency	Percentage
Strongly agree	13	30%
Agree	16	36%
Neutral	11	25%
Disagree	4	9%
Strongly disagree	0	0%
Total	44	100%

Table 26 – extent of resistance to change by the construction industry.

4.5.8 Legal issues and insufficient governmental support

As it is today, the building sector in South Africa operates under a set of regulations, guidelines, and standards that dictate the proper procedures. However, these established legal frameworks might pose challenges to integrating robotics and automation, as they may not be sufficiently adapted to accommodate these new technologies. Additionally, without governmental incentives such as tax breaks or subsidies, there could be less motivation for companies to invest in costly new technologies like robotics and automation. Respondents were queried on this. The question put forward was: *“To what extent do you agree that legal issues and insufficient governmental support act as barriers to adopting robotics and construction automation?”* Table 27 outlines their responses.

Legal issues and insufficient governmental support	Frequency	Percentage
Strongly agree	15	34%
Agree	12	27%
Neutral	14	32%
Disagree	2	5%
Strongly disagree	1	2%
Total	44	100%

Table 27 – extent of legal issues and insufficient governmental support

4.5.9 Fragmentary nature and size of the construction industry

When the building sector is said to be "fragmented," it implies that the sector is made up of numerous small, specialised organisations instead of a few big ones. The one-size-fits-all approach of some robotic and automation solutions may not suit their unique needs, possibly leading to lack of adoption by these companies. The survey tested whether construction professionals agreed or disagreed with this - 18% “Agree”, 41% “Strongly agree”, 7% “Disagree”, 32% “Neutral”, and 2% “Strongly disagree”. Reference is made to Table 28.

Fragmentary nature and size of the construction industry	Frequency	Percentage
Strongly agree	8	18%
Agree	18	41%
Neutral	14	32%
Disagree	3	7%
Strongly disagree	1	2%
Total	44	100%

Table 28 – extent of fragmentary nature and size of the construction industry

4.5.10 Overall extent of barriers

Figure 16 is a bar chart that outlines a comprehensive overview of the perceived obstacles to acceptance of automation and robotics within the construction sector. Leading the chart is the barrier "High costs of acquiring technologies," scoring an impressive 4.5. Coming in last is “Incompatible with current construction practices’ with a mean score of 3.3. A close examination of the chart reveals that in all cases the barriers did not receive a score equal to or below 3, which can be considered a mid-range score. This tells us that, on a general level, research participants all agree that the 9 barriers act against the implementation of robotics and construction automation.

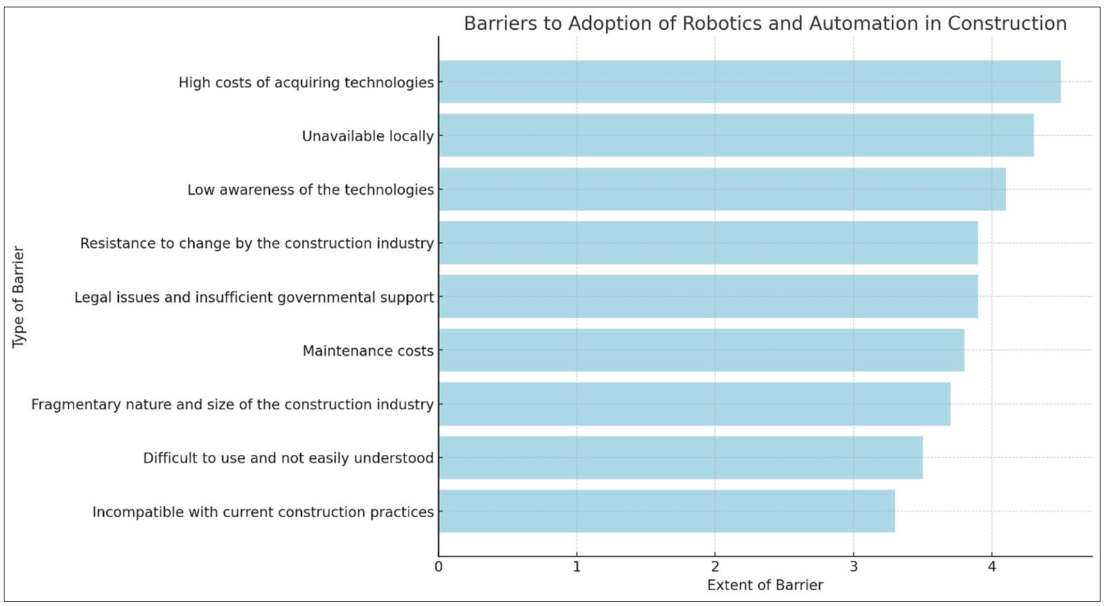

Figure 16 – overall extent of barriers to the adoption of robotics and automation

4.6. Summary

This chapter focused only on presenting the research findings of this study. A survey was utilised to attain the information, 44 responses were received. Holistically, the survey was partitioned into four parts.

Section A reported on the research respondents’ demographics in a bid to evaluate their characteristics in terms of gender, age and so on. The findings indicated that there was more participation of men than women in the study, split into 78% and 22% respectively. The respondents had a mean age of 36 years old. Most of the respondents worked in consulting environments. The experience level of most of the participants was between 6 and 10 years.

Section B of the survey reported findings about the awareness level of types of automation and robotics, a total of 10 types was identified. CAD (Computer-aided Design) was the most recognised by the respondents. GPS (Global Positioning System) and prefabrication construction followed closely. The least recognised were robotic arms.

Section C outlined findings on the benefits of adopting robotics and construction automation. A total of 7 benefits were considered, with time saving and increased productivity leading the pack. Generally, all the perceived benefits were rated highly on the survey.

Section D concluded the survey by gathering information on the obstacles preventing implementation of robotics and construction automation. 9 barriers were reported on. The ranking showed that the number one barrier was "High costs of acquiring technologies". The information is best condensed in Table 29 underneath.

Section	Component
A	Background information
B	Awareness of robotics and automation
C	Benefits of robotics and automation
D	Barriers to adoption of robotics and automation

Table 29 – summary of findings

5. CHAPTER 5: DISCUSSION OF FINDINGS

5.1. Introduction

The insights from the study are unpacked in this chapter. It is imperative to first ponder on what the research sought to achieve by reviewing the research questions. The intent of the three research questions was, first, to understand the awareness level of the types of robotics and automation technologies. Secondly, to discover the potential benefits of implementing robotics and construction automation in the building sector. Thirdly, the goal of the study was to also reveal the obstacles to adoption of robotics and construction automation. The outcomes of this research will be discussed inside this framework. As such, awareness, benefits, and barriers will each be discussed under separate headings.

To ensure that the discussion chapter is well-structured and offers more value to the reader, the writing framework proposed by Dunton (2022) was followed. In order to write a compelling discussion chapter, the author suggests that researchers should first explain why their findings are important. He also proposes that researchers summarize key findings and then link them to the original research questions. The contextualisation of findings is also critical, it must be shown how the findings fit in with previous research. In instances where unexpected results come up, researchers should not avoid them but tackle them head on by providing reasonable explanations for their occurrence.

5.2. Demographics

The sample of this study was split into 78% males and 22% females. This gender distribution is reflective of that of the construction industry in South Africa. Ngqetsu (2023) states that males, by numbers, still dominate the construction industry. The author backs her claim by quoting current statistics issued by Statistics South Africa. Therefore, the skew towards more males in the sample is understandable.

The study sample we examined has an average age of 36 years. According to the 2022 South African census, the median age in the country is 28 years (StatsSA, 2022). The median age serves as a measure of a population's youthfulness, maturity, or aging. This data suggests that South Africa's inhabitants are predominantly young. When comparing the average age of our sample (36 years) to the country's median age (28 years), it could be accepted that the sample is fairly mirroring the age of the South African populace.

There is a balanced mix of level of experience of the participants. A key element of this is that the responses received will show the varying opinions of a wide spectrum, allowing the student to deeply probe the topic.

Most of the research participants (64%) are employed as consultants. Consultants mainly focus on the design aspect of construction. Given their role, it's reasonable to anticipate that they would possess greater familiarity with design automation technologies. This is exactly what the findings of this study show i.e. Computer-aided Design (CAD) is the most recognised technologies.

5.3. Awareness

Research Question 1: What is the level of awareness of the existing types of robotics and construction automation currently in use in the construction industry?

The discussion of the findings related to the awareness of robotics and construction automation has been partitioned into two parts. One part focuses only on the level of awareness of specific technologies wherein three levels are considered i.e. high awareness, moderate awareness and low awareness. The technologies are grouped into these three levels based on the familiarity ratings given by participants. The second part deals with the influence of demographics, such as gender and age on awareness levels.

5.3.1 Level of awareness

There are three technologies that have been found to fall within the high awareness category. They are *Computer-aided Design (CAD)* with an average score of 4.2, *Global Positioning System (GPS)* with a mean awareness score of 4.1 and *Off-Site Prefabrication* which was rated 4.0.

The high awareness level of CAD could be ascribed to the construction sector's long history and reliance on the technology. Autodesk first introduced AutoCAD as the first affordable 3D design CAD system in 1982 (Clayton, 2005). In numerous technical institutes and universities, courses in CAD have been integrated as a mandatory part of the curriculum (Rahman, 2019). Fadamiro and Oke (2019) reached similar findings in Nigeria where they found that CAD was ranked as the most familiar technology by construction industry professionals. According to Siminialayi and Fomsi (2023) CAD has remained a formidable tool within the engineering design space.

Similarly, the participants' extensive familiarity with off-site prefabrication can be linked to its widespread and enduring use in the construction sector. For example, the Hong Kong Housing Authority first embraced the utilisation of off-site prefabrication 36 years ago in 1988 (Tam et al., 2006). According to Lu et al. (2018), in 2016 the government of China announced a 10-year plan aiming to use prefabrication methods in 30% of all new building constructions across the nation.

Technologies like *Sensing Technologies (3.7), Drones (3.6), 3D Printing (3.4),* and *Building Information Modeling (BIM) (3.4)* fall into the moderate awareness category.

The moderate awareness of 3D printing (3.4) reflects its growing but still emerging status in the industry. Reference is made to Oke, Atofarati and Bello (2022)'s study where the authors were investigating the awareness level of 3D Printing in Nigeria. It was found that 65,8% of the respondents were aware of 3D Printing, indicating a growing familiarity of the technology even in developing countries. While the application of drones in military settings has been extensively recorded, their increasing adoption in various other fields, such as construction, has gained momentum more recently, a development highlighted by Ciampa, De Vito, and Pecce (2019).

In this study, participants showed a moderate awareness of BIM (Building Information Modeling), which is slightly different from what Roseli, Abas, and

Ibrahim found in their 2023 study in Malaysia. In Malaysia, most construction professionals were quite familiar with BIM. This higher awareness level in Malaysia might be due to the government's decision in 2009 to start using BIM in the infrastructure sector (Haron et al., 2017).

On the other on the scale, *Robotic Arms (2.5), Virtual Reality (3.2),* and *Autonomous Vehicles (3.0)* have lower awareness levels.

A significant point is that Virtual Reality (VR) relies on Building Information Modelling (BIM) and Computer-Aided Design (CAD) as they are the foundational tools for generating models that are essential for VR applications (Ahmed, Hossain & Hoque, 2017). This reliance might be the reason for the observed difference in awareness levels among these technologies.
In general, industry professionals might first become adept at using CAD and BIM, which then paves the way for them to gain an understanding of VR technology.

5.3.2 Influence of demographics on awareness

To further explore the awareness levels of robotics and automation among construction professionals, the study conducted a One-Way ANOVA analysis. This test compared the average values (means) of parameters such as gender, age, educational background, experience level, job title and employer type. The results are shown in Table 12 and discussed below.

Awareness levels regarding robotics and construction automation were found to vary according to the job title, as indicated by a p-value of 0.03. This suggests that a respondent's position in their organization plays a role in shaping their awareness. Such a finding is logical, considering that professionals primarily engaged in design tasks are likely to be more familiar with design-related technologies, whereas those working on-site might have greater knowledge of on-site automation technologies.

With a p-value of 0.02, work experience of construction professionals has an influence on the awareness level of construction automation and robotics. This suggests that professionals with more years of experience are prone to have a greater level of awareness as opposed to those with fewer years in the field. The rationale behind this is understandable, as longer-serving individuals in the construction sector are more probable to have participated in a greater number of projects, thereby increasing their chances of encountering robotic technologies in their work environment.

Regarding the influence of the type of employer on awareness levels, the analysis showed a p-value of 0, lower than the 0.05 benchmark, indicating statistical significance. This means that the type of employer a participant works for has a noticeable impact on their awareness of robotics and construction automation. For instance, individuals employed by private clients may have different levels of awareness compared to those working for government entities. Similarly, the awareness levels between contractors and consultants could vary. Contractors, often more involved in on-site activities, might be more familiar with on-site technologies, whereas consultants, who typically focus on design aspects, might have a higher awareness of design technologies. This result is akin to the finding related to the impact of job titles on awareness levels, as both are connected to the employment context of the construction professionals.

5.4. Benefits

Research question 2: What are the perceived benefits of adopting the use of robots and automation in the South African construction industry?

The research question is centred on uncovering and understanding the various advantages that the construction industry could realize through the implementation of robotics and automation technologies. In an effort to comprehensively address this, an appraisal of relevant literature on the subject was conducted to gather insights This extensive review culminated into a list of 7 benefits that these technologies could offer, and they are: *occupational safety improvements, higher quality and accuracy, increased productivity, reduced material disposal, cost reduction, time saving* and *less human labour.*

In this study it was found that *increased productivity* was the most significant benefit of implementing automation and robotics in the construction industry, with an average score of 4.3. This finding, however, seems to contradict what Onososen and Musonda (2022) in their study. They asked experts in the field to prioritise a list of benefits, and in their findings, occupational safety came out as the top benefit. This difference in findings is quite intriguing and suggests that perceptions of the primary benefits of these technologies in construction can vary greatly depending on the group being surveyed.

Surprisingly, *less human labour* is rated highly at number 3 on the list of potential benefits. Technically, this finding does not raise any eyebrows. However, in a nation such as South Africa, which faces a serious crisis of joblessness, this benefit becomes a socio-economic contradiction. While technically beneficial, reducing dependence on human labour through automation conflicts with the broader need for job creation in the economy. South Africa aspires to shrink the rate of unemployment below 6% by 2030 (National Planning Commission, 2013).

In a developing country where the focus should be on reducing high unemployment rates, any technology that potentially reduces the number of jobs becomes problematic. This scenario is quite different from what one would find in developed countries, where labour shortages are a more pressing issue. In such countries, the reduction of human labour due to automation can be a significant advantage, helping to address workforce gaps and improve productivity without the socio-economic concern of exacerbating unemployment.

The survey revealed that cost reduction is perceived as a relatively minor benefit by the participants, ranking low on the list of benefits. This viewpoint is further reinforced by the identification of high initial costs as the primary barrier to adopting these technologies. Essentially, the participants do not see significant cost savings in implementing robotics and automation in the industry. They express a concern that not only will these technologies not lead to substantial financial savings, but their initial implementation is also seen as prohibitively expensive. These concerns about costs and initial investment are major factors that might hinder the implementation of robotics and automation technologies in the construction sector.

5.5. Barriers

Research question 3: What are the perceived barriers to adoption of robotics and automation in the South African construction industry?

The discoveries of this research answered this research question adequately. Firstly, a sum of 9 barriers were uncovered in scholarly articles. These were *incompatibility with current construction practices, maintenance costs, legal issues, difficult to use, low awareness, high costs of acquiring the technology, resistance to change, unavailability locally and nature of the construction industry.* By virtue of bringing these barriers to light, research question 3 is partly answered.

Secondly, the barriers were then ranked in terms of extent of their influence on adoption of robotics and automation. The highest ranked barrier is *high cost of acquiring technologies*. This barrier relates to the initial money that must be spent in order to purchase the technologies. The South African construction sector, as noted by Tubane (2017), is predominantly made up of many small companies that often have limited financial resources. These firms are particularly sensitive to costs, which may make them sceptical to devote significant sums of money in new, unfamiliar technologies - especially when there are uncertainties regarding the immediate and tangible benefits of such investments.

Pradhananga et al. (2021) performed similar research in the United States of America where they sought to identify challenges to adoption of robotics in that country. The conclusions drawn by the authors mirror those found in this study. The authors found that the high initial capital investment is what stops most companies from buying the technology. This is worsened, the authors propose, by the uncertainty of ROI and thin profit margins of the construction industry. In another separate study in Malaysia, Mahbub (2012) also found that construction companies rated initial capital investment as the biggest barrier to adoption of robotic technologies.

5.6. Summary

This chapter entailed the discussion of the study findings in terms of the three research questions.

Firstly, discussions surrounding the first question were presented concerning the awareness level of robotics and automation by construction professionals. It was observed that CAD technology is the most recognised among participants, primarily due to its longstanding presence in the construction industry. Conversely, technologies such as virtual reality are less familiar, likely owing to their relatively recent introduction to the industry. The study also explored the influence of demographics, including experience, job title, and employer type, on the level of awareness among participants.

The second aspect of the research delved into the potential benefits of implementing robotics and automation technologies. The findings indicated that most participants view increased productivity as the most significant benefit. However, the study also addressed the complexities associated with the reduction of human labour, a matter of specific significance in the perspective of South Africa.

Lastly, the research focused on the obstacles to implementing robotics and automation in the construction sector. The primary challenge identified was the substantial initial investment required for these technologies. This barrier has been recognized as a common issue in the global context, as corroborated by various researchers.

6. CHAPTER 6: CONCLUSION, LIMITATIONS AND RECOMMENDATIONS

6.1. Introduction

This final chapter summarises the study's conclusions regarding the awareness, benefits, and barriers of robotics and construction automation technologies in the building sector. It also discusses the research limitations and offers recommendations for enhancing the adoption of these technologies. Concluding the chapter are proposed directions for future research in this evolving field.

6.2. Conclusion

Broadly, the study primarily aimed to gauge construction professionals' understanding and knowledge of robotics and automation within their industry. This goal was divided into three key areas: assessing the awareness of different robotic and automation technologies, exploring the potential advantages of utilising these technologies, and identifying the challenges or obstacles hindering their widespread adoption in the construction sector.

6.2.1. Awareness

The first step in any effort to adopt the utilisation of robotics and automation in the construction sector is to be aware of the existence of the technologies. The study successfully mapped the current landscape of awareness regarding robotics and automation among construction professionals.

6.2.2. Benefits

With increased productivity noted as the top benefit, the research also exposed other potential benefits that can be accessed by implementing the use of robotics and automation in the construction sector.

6.2.3. Barriers

The adoption of robotics and automation can only happen once its barriers and their corresponding severity are well understood by the construction industry. Solutions can then be put in place to counter the friction caused by these barriers. The study has identified the main obstacles to the adoption of robotics and automation, finding that the hefty prices of acquiring the technologies is the core barrier, a challenge that is common not only in South Africa but also globally.

6.3. Limitation

The study's focus was limited to participants from the Limpopo province, presenting a significant geographical limitation. By concentrating solely on this region, the research overlooked perspectives and insights from professionals in other provinces, which could have potentially enriched and broadened the findings. Furthermore, the methodology employed for participant selection, convenience sampling, and the limited number of respondents also constitute a methodological limitation. The sampling was not randomised. Instead, the researcher relied on familiar contacts within the construction industry, which may have introduced a degree of bias and limited the diversity of viewpoints. A larger and more randomised sample would have likely provided a wider array of views and a comprehensive understanding of the topic at hand.

6.4. Recommendations

In light of the insights gained from this study, this research puts forth several recommendations aimed at enhancing the awareness and facilitating the wider implementation of robotics and automation within the construction sector.

- It is crucial to focus on improving training and education in emerging technologies. This initiative should aim to raise awareness and skill levels, particularly in areas like Virtual Reality, where there is currently less familiarity.

- Additionally, the involvement of the government is essential. Taking cues from other countries' successful implementations, such as Malaysia's promotion of Building Information Modeling (BIM), the South African government could introduce incentives and support programs for companies adopting these advanced technologies.

- There's also a need for targeted awareness campaigns, especially for technologies like 3D Printing, where current awareness is moderate. These campaigns would help in showcasing the real-world uses and benefits of these technologies in the construction sector.

- It is imperative to address the socio-economic impacts, especially concerning the reduction of labour through automation. This is a sensitive issue in the context of South Africa's high joblessness rates. Conducting further studies to explore how technological advancement can be balanced with job creation is crucial. Identifying new job roles that emerge from the adoption of these technologies could be a part of this exploration.

- Lastly, addressing the cost-related challenges is vital. Since cost reduction is not perceived as a major benefit and high initial investment is a significant barrier, developing strategies for effective cost management is imperative. This could include exploring various financing options, implementing these technologies in phases, and considering cost-sharing models. Such strategies would help construction companies manage the financial aspects of adopting new technologies, making it a more feasible and attractive proposition.

6.4.1. Practical implications

The results and recommendations of this research have a wider impact on the industry itself, the kind of skills that workers will need, how technology companies might respond, and even the way people think about construction. Let's dive into these broader effects:

- The study could inform policymakers about the need for regulations and standards that address the integration of advanced technologies in construction, ensuring safe and effective implementation.

- Educational institutions might start considering revising or updating their curriculum to include more focused training on robotics and automation in construction, preparing future professionals for the evolving industry demands.

- The insights might attract investors or funding bodies to support research and development in construction technology, seeing the potential for innovation and profitability.

- The findings could encourage technology companies to develop new or improved automation solutions tailored to the construction industry's needs, recognizing a potential market growth area.

6.4.2. Future studies

The following areas can be explored in future studies to gain more insights for the benefit of the South African construction sector:

- Long-term cost-benefit analysis of robotics and automation in construction: A study focusing on the long-term financial impacts of adopting these technologies. This could include analysing the return on investment over an extended period and the overall cost savings in terms of labour, time, and materials.

- Training models for construction automation technologies: Investigating effective approaches for educating construction workers and management in the use of these new technologies.
- The impact of robotics and automation on job creation and workforce development: Investigating how these technologies affect employment in the construction sector. This type of research could investigate the balance between job displacement due to automation and the cultivation of employment growth in the management and maintenance of these technologies.

6.5. Summary

This research offers valuable perspectives into the current state of robotics and automation in the South African construction sector, identifying key zones for future development, policymaking, and research. The findings offer a foundation for stakeholders to strategically approach the implementation of these technologies, considering both their potential benefits and the challenges they pose.

REFERENCES

Abdel-Wahab, M., & Vogl, B. (2011). Trends of productivity growth in the construction industry across Europe, US and Japan. *Construction management and economics*, *29*(6), 635-644.

Agenda, I. (2016). Shaping the future of construction a breakthrough in mindset and technology. In *World Economic Forum*.

Aghimien, D. O., Aigbavboa, C. O., Oke, A. E., & Thwala, W. D. (2020). Mapping out research focus for robotics and automation research in construction-related studies: A bibliometric approach. *Journal of Engineering, Design and Technology*, *18*(5), 1063-1079.

Ahmed, S. (2018). A review on using opportunities of augmented reality and virtual reality in construction project management. *Organization, technology & management in construction: an international journal*, *10*(1), 1839-1852.

Ahmed, S., Hossain, M. M., & Hoque, M. I. (2017). A brief discussion on augmented reality and virtual reality in construction industry. *Journal of System and Management Sciences*, *7*(3), 1-33.

Andigani, R. (2020). Urgency Ethics in Robotics. *Worcester Polytechnic Institute: Electronic Projects Collection*, *19*.

Akinradewo, O., Oke, A., Aigbavboa, C., & Mashangoane, M. (2018). *Willingness to Adopt Robotics and Construction Automation in the South African Construction Industry*. In *proceedings of the Int. Conf. on Ind. Eng. and Operat. Magt.* (p. 201).

Albus, J. S. (1986). Trip report: Japanese progress in robotics for construction. *Robotics*, *2*(2), 103-112.

Al-Ashmori, Y. Y., Othman, I., Rahmawati, Y., Amran, Y. M., Sabah, S. A., Rafindadi, A. D. U., & Mikić, M. (2020). BIM benefits and its influence on the BIM implementation in Malaysia. *Ain Shams Engineering Journal*, *11*(4), 1013-1019.

Adami, P., Becerik-Gerber, B., Soibelman, L., Doleck, T., Copur-Gencturk, Y., & Lucas, G. (2020, December). An immersive virtual learning environment for worker-robot collaboration on construction sites. In *2020 Winter Simulation Conference (WSC)* (pp. 2400-2411). IEEE.

Bernold, L. E. (1987). *Automation and robotics in construction: a challenge and a chance for an industry in transition*. International Journal of Project Management, 5(3), 155-160.

Bierman, M., Marnewick, A., & Pretorius, J. H. C. (2016). Productivity management in the South African civil construction industry-factors affecting construction productivity. *Journal of the South African Institution of Civil Engineering*, *58*(3), 37-44.

Bock, T. (2015). The future of construction automation: Technological disruption and the upcoming ubiquity of robotics. *Automation in Construction*, *59*, 113-121.

Begum, M. M. R., Chandramouli, M. S., & Gowtham, M. T. (2020). *Design And Development Of Dual Axis Control Robot For Writing Robot Through Speech Recognition*. International Research Journal of Modernization in Engineering Technology and Science.

Barbosa, F., Woetzel, J., & Mischke, J. (2017). *Reinventing Construction: A Route of Higher Productivity*. McKinsey Global Institute.

Bohn, J. S., & Teizer, J. (2010). Benefits and barriers of construction project monitoring using high-resolution automated cameras. *Journal of construction engineering and management*, *136*(6), 632-640.

Burgess, G., Jones, M., & Muir, K. (2018). BIM in the UK house building industry: opportunities and barriers to adoption. *University of Cambridge: Cambridge, UK*.

Bruner, P. L. (2007). The historical emergence of construction law. *Wm. Mitchell L. Rev.*, *34*, 1.

Brynjolfsson, E., & McAfee, A. (2011). *Race against the machine: How the digital revolution is accelerating innovation, driving productivity, and irreversibly transforming employment and the economy*. Brynjolfsson and McAfee.

Calis, G., Deora, S., Li, N., Becerik-Gerber, B., & Krishnamachari, B. (2011, June). Assessment of WSN and RFID technologies for real-time occupancy information. In *Proceedings of the 28th International Symposium on Automation and Robotics in Construction (ISARC 2011), Seoul, Korea* (Vol. 29).

Chen, Q., de Soto, B. G., & Adey, B. T. (2018). Construction automation: Research areas, industry concerns and suggestions for advancement. *Automation in construction*, *94*, 22-38.

Cottle, E. (2014). The Transformation of the Construction Sector in South Africa since apartheid: Social inequality and labour. *Unpublished thesis. Brazil: State University of Campinas*.

Construction Industry Development Board. (2015). Labour & Work Conditions in the South African Construction Industry. Retrieved from http://www.cidb.org.za/publications/Documents/Labour%20and%20Work%20Conditions%20in%20the%20South%20African%20Construction%20Industry;%20Status%20and%20Recommendations.pdf

Chea, C. P., Bai, Y., Pan, X., Arashpour, M., & Xie, Y. (2020). An integrated review of automation and robotic technologies for structural prefabrication and construction. *Transportation Safety and Environment*, *2*(2), 81-96.

Choy, L. T. (2014). The strengths and weaknesses of research methodology: Comparison and complimentary between qualitative and quantitative approaches. *IOSR Journal of Humanities and Social Science*, *19*(4), 99-104.

Changali, S., Mohammad, A., & Nieuwland, M. V. (2015). The construction productivity imperative.

Clayton, M. J. (2005). How I stopped worrying and learned to love AutoCAD. *Smart Architecture: Integration of Digital and Building Technologies*, 94-103.

Crawford, P., & Vogl, B. (2006). Measuring productivity in the construction industry. *Building Research & Information*, *34*(3), 208-219.

Cai, S., Ma, Z., Skibniewski, M. J., & Bao, S. (2019). Construction automation and robotics for high-rise buildings over the past decades: A comprehensive review. *Advanced Engineering Informatics*, *42*, 100989.

Crotty, R. (2013). *The impact of building information modelling: transforming construction*. Routledge.

Construct Africa. (2022). *The South African Construction Market Report.* Retrieved from https://www.constructafrica.com/sites/default/files/2022-07/SOUTH%20AFRICA%20CONSTRUCTION%20MARKET%20REPORT%2020 22%20-%20SAMPLE.pdf

da Silva, N. P., Eloy, S., & Resende, R. (2022). Robotic construction analysis: simulation with virtual reality. *Heliyon*, *8*(10), e11039.

Darlow, G., Rotimi, J. O., & Shahzad, W. M. (2021). Automation in New Zealand's offsite construction (OSC): a status update. *Built Environment Project and Asset Management*.

Delgado, J. M. D., Oyedele, L., Ajayi, A., Akanbi, L., Akinade, O., Bilal, M., & Owolabi, H. (2019). Robotics and automated systems in construction: Understanding industry-specific challenges for adoption. *Journal of Building Engineering*, *26*, 100868.

Dadhich, S., Bodin, U., & Andersson, U. (2016). Key challenges in automation of earth-moving machines. *Automation in Construction*, *68*, 212-222.

Dibra, M. (2015). Rogers theory on diffusion of innovation-the most appropriate theoretical model in the study of factors influencing the integration of sustainability in tourism businesses. *Procedia-Social and Behavioral Sciences*, *195*, 1453-1462.

Dodge. (2017). Smart Market Report – The Business Value of BIM for Infrastructure. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/us/Documents/finance/us-fas-bim-infrastructure.pdf

Domdouzis, K., Kumar, B., & Anumba, C. (2007). Radio-Frequency Identification (RFID) applications: A brief introduction. *Advanced Engineering Informatics*, *21*(4), 350-355.

Douer, N., & Meyer, J. (2020). The responsibility quantification model of human interaction with automation. *IEEE Transactions on Automation Science and Engineering*, *17*(2), 1044-1060.

D'Uva, D., Rolando, A., Piumatti, P., Zanchetta, C., & Janovitz, A. (2009). Definition and representation of complex architectural shapes. *Experiences in Advanced Courses at the Faculty of Architecture in Milano*.

Dunton, R. (2022). How to Read a Research Paper. *Retrieved from San José State University Wrifing Center: https://www. sjsu. edu/wrifingcenter/docs/handouts/How% 20to% 20Read% 20a% 20Research% 20Paper. pdf*.

Eastman, C. M., Eastman, C., Teicholz, P., Sacks, R., & Liston, K. (2011). *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*. John Wiley & Sons.

Ebneyamini, S., & Sadeghi Moghadam, M. R. (2018). Toward developing a framework for conducting case study research. *International journal of qualitative methods*, *17*(1), 1609406918817954.

ECSO (2021). *Digitalisation in the construction sector,* European Construction Sector Observatory

Endsley, M. R. (2017). Autonomous driving systems: A preliminary naturalistic study of the Tesla Model S. *Journal of Cognitive Engineering and Decision Making*, *11*(3), 225-238.

Elattar, S. M. S. (2008). Automation and robotics in construction: opportunities and challenges. *Emirates journal for engineering research*, *13*(2), 21-26.

Ensafi, M., Thabet, W., Devito, S., & Lewis, A. (2021). Field testing of mixed reality (MR) technologies for quality control of as-built models at project handover: a case study. *EPiC Series in Built Environment*, *2*, 246-254.

Engsley, M. R., Onal, E., & Kaber, D. B. (1997, June). The impact of intermediate levels of automation on situation awareness and performance in dynamic control systems. In *Proceedings of the 1997 IEEE Sixth Conference on Human Factors and Power Plants, 1997.'Global Perspectives of Human Factors in Power Generation'* (pp. 7-7). IEEE.

El-Sayegh, S., Romdhane, L., & Manjikian, S. (2020). A critical review of 3D printing in construction: Benefits, challenges, and risks. *Archives of Civil and Mechanical Engineering*, *20*(2), 1-25.

Ergun, H. (2015). Monitoring physiological reactions of construction workers in virtual environment: A feasibility study using affective sensing technology.

Falorca, J. F., Miraldes, J. P., & Lanzinha, J. C. G. (2021). New trends in visual inspection of buildings and structures: Study for the use of drones. *Open Engineering*, *11*(1), 734-743.

Fadamiro, O. P., & Oke, A. E. (2019). The Level of awareness of automation technology in the construction industry. *IOP Conference Series.Earth and Environmental Science, 331*(1)https://doi.org/10.1088/1755-1315/331/1/012013

Folkesson, P., & Lönnroos, R. (2018). Construction automation: Assessment of state of the art and future possibilities.

Frey, C. B., & Osborne, M. A. (2017). The future of employment: How susceptible are jobs to computerisation?. *Technological forecasting and social change*, *114*, 254-280.

Galić, M. (2022). DIGITALIZATION AND AUTOMATION IN CONSTRUCTION PROJECT’S LIFE-CYCLE: A REVIEW.

Gharbia, M., Chang-Richards, A., Lu, Y., Zhong, R. Y., & Li, H. (2020). Robotic technologies for on-site building construction: A systematic review. *Journal of Building Engineering*, 101584.

Graetz, G., & Michaels, G. (2018). Robots at work. *Review of Economics and Statistics*, *100*(5), 753-768.

Grau, D., Zeng, L., & Xiao, Y. (2012). Automatically tracking engineered components through shipping and receiving processes with passive identification technologies. *Automation in Construction*, *28*, 36-44.

Gu, Y., Lo, A., & Niemegeers, I. (2009). A survey of indoor positioning systems for wireless personal networks. *IEEE Communications surveys & tutorials*, *11*(1), 13-32.

Guo, H., Yu, Y., & Skitmore, M. (2017). Visualization technology-based construction safety management: A review. *Automation in Construction*, *73*, 135-144.

Haron, N. A., Raja Soh, R. P. Z. A., & Harun, A. N. (2017). Implementation of Building Information Modelling (BIM) in Malaysia: A Review. *Pertanika Journal of Science & Technology*, *25*(3).

Hason, S. F. (1994). *Feasibility and implementation of automation and robotics in Canadian building construction operations* (Doctoral dissertation, Concordia University).

Hatoum, M. B., & Nassereddine, H. (2020). Developing a framework for the implementation of robotics in construction enterprises. In *EG-ICE 2020 Workshop on Intelligent Computing in Engineering, Proceedings* (pp. 453-462).

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence-based nursing*, *18*(3), 66-67.

Hilfert, T., Teizer, J., & König, M. (2016). First person virtual reality for evaluation and learning of construction site safety. In *ISARC. Proceedings of the*

International Symposium on Automation and Robotics in Construction (Vol. 33, p. 1). IAARC Publications.

Hoeft, M., Kronsell, S., Manzoor, S., Johansson, F., Gustafson, A., von Haslingen, T., & Eriksson, K. (2022). Construction automation and robotics in infrastructure.

Hong, C. S. (2020). *Automation and Artificial intelligence for Naval ISR: US Navy VS. China's Navy*. NAVAL POSTGRADUATE SCHOOL MONTEREY CA MONTEREY United States.

Hsiao, J. C. (1994). *A comparison of construction automation in major constraints and potential techniques for automation in the United States, Japan, and Taiwan* (Doctoral dissertation, Massachusetts Institute of Technology).

Hughes, W. P., & Hillebrandt, P. M. (2003). Construction industry: historical overview and technological change.

Ibrahim, H. S., Hashim, N., & Jamal, K. A. A. (2019, November). The potential benefits of building information modelling (BIM) in construction industry. In *IOP Conference Series: Earth and Environmental Science* (Vol. 385, No. 1, p. 012047). IOP Publishing.

International Data Corporation. (2020). Worldwide spending on robotics systems and drones. Retrieved from https://www.idc.com/getdoc.jsp?containerId= prUS45800320.

International Federation of Robotics. (2020). World Robotics Report. Retrieved from PowerPoint-Präsentation (ifr.org)

Jayaraj, A., & Divakar, H. N. (2018, June). Robotics in construction industry. In *IOP Conference Series: Materials Science and Engineering* (Vol. 376, No. 1, p. 012114). IOP Publishing.

Jiang, R., Mao, C., Hou, L., Wu, C., & Tan, J. (2018). A SWOT analysis for promoting off-site construction under the backdrop of China's new urbanisation. *Journal of Cleaner Production*, *173*, 225-234.

Josephson, P. E., & Hammarlund, Y. (1999). The causes and costs of defects in construction: A study of seven building projects. *Automation in construction*, *8*(6), 681-687.

Jud, D., Leemann, P., Kerscher, S., & Hutter, M. (2019). Autonomous free-form trenching using a walking excavator. *IEEE Robotics and Automation Letters*, *4*(4), 3208-3215.

Kamaruddin, S. S., Mohammad, M. F., & Mahbub, R. (2016). Barriers and impact of mechanisation and automation in construction to achieve better quality products. *Procedia-Social and Behavioral Sciences*, *222*, 111-120.

Kale, S., & Arditi, D. (2010). Innovation diffusion modeling in the construction industry. *Journal of construction engineering and management*, *136*(3), 329-340.

Kangari, R., & Yoshida, T. (1990). *Automation in construction*. Robotics and autonomous systems, 6(4), 327-335.

Kijima, K., & Furukawa, Y. (2003). Automatic collision avoidance system using the concept of blocking area. *IFAC Proceedings Volumes*, *36*(21), 223-228.

Kim, M. J., Chi, H. L., Wang, X., & Ding, L. (2015). Automation and robotics in construction and civil engineering. *Journal of Intelligent & Robotic Systems*, *79*(3-4), 347.

Kitahara, S., Nitta, Y., & Nishigaki, S. (2019). Efforts to Unmanned Construction for Post-disaster Restoration and Reconstruction. In *ISARC. Proceedings of the International Symposium on Automation and Robotics in Construction* (Vol. 36, pp. 1155-1162). IAARC Publications.

Kivunja, C., & Kuyini, A. B. (2017). Understanding and applying research paradigms in educational contexts. International Journal of higher education, 6(5), 26-41.

Klinov, P. (2019). Construction robotics present implementation and prospects.

Kopsida, M., Brilakis, I., & Vela, P. A. (2015, October). A review of automated construction progress monitoring and inspection methods. In *Proc. of the 32nd CIB W78 Conference 2015* (pp. 421-431).

Kropp, C., Koch, C., & König, M. (2018). Interior construction state recognition with 4D BIM registered image sequences. *Automation in construction*, *86*, 11-32.

Kumar, R. (2018). *Research methodology: A step-by-step guide for beginners*. Sage.

Kuczmarski, T. D. (1996). Innovation: Leadership strategies for the competitive edge. *(No Title)*.

Leung, S. W., Mak, S., & Lee, B. L. (2008). Using a real-time integrated communication system to monitor the progress and quality of construction works. *Automation in construction*, *17*(6), 749-757.

Mahbub, R. (2008). *An investigation into the barriers to the implementation of automation and robotics technologies in the construction industry* (Doctoral dissertation, Queensland University of Technology).

Mahbub, R. (2012). Readiness of a developing nation in implementing automation and robotics technologies in construction: a case study of Malaysia. *Journal of Civil Engineering and Architecture*, *6*(7), 858.

Mane, P. P., & Patil, J. R. (2015). Quality management system at construction project: A questionnaire survey. *Int. Journal of Engineering Research and Applications*, *5*(3), 126-130.

Maree, K. (2019). First steps in research. Pretoria. *South Africa: Van Schaik http://www. theiia. org/chapters/pubdocs/242/Internal_Controls_Basics_IIA_0*, *40709*.

Mascaro, R., Wermelinger, M., Hutter, M., & Chli, M. (2021). Towards automating construction tasks: Large-scale object mapping, segmentation, and manipulation. *Journal of Field Robotics*, *38*(5), 684-699.

Mehfooz, N., & Saeed Lodhi, D. (2015). Implementation barrier of ISO 9001 with in service and manufacturing organizations in Pakistan. *IOSR Journal of Business and ManagementVer*.

Melenbrink, N., Werfel, J., & Menges, A. (2020). On-site autonomous construction robots: Towards unsupervised building. *Automation in Construction*, *119*, 103312.

Melnikovas, A. (2018). Towards an explicit research methodology: Adapting research onion model for futures studies. *Journal of Futures Studies*, *23*(2), 29-44.

Mhaisalkar, M., Chaudhari, N., & Kawale, T. (2020). CLINIC AUTOMATION SYSTEM USING PIC CONTROLLER. *Editorial Board*, *9*(7).

Mirjan, A., Augugliaro, F., D'Andrea, R., Gramazio, F., & Kohler, M. (2016). Building a bridge with flying robots. *Robotic fabrication in architecture, art and design 2016*, 34-47.

Mlotshwa, S. H. (2019). *The influence of networking on small medium enterprise performance in Gauteng, South Africa* (Doctoral dissertation).

Morales, G., Herbzman, Z., & Najafi, F. T. (1999). Robots and construction automation. *Automation and Robotics in Construction XVI UC3M*, *283*, 288.

Moselhi, O., Bardareh, H., & Zhu, Z. (2020). Automated data acquisition in construction with remote sensing technologies. *Applied Sciences*, *10*(8), 2846.

Nadarajah, N. (2018). *Development of concrete 3D printing* (Master's thesis, Aalto University).

Onososen, A. O., & Musonda, I. (2022). Perceived benefits of automation and artificial intelligence in the AEC sector: An interpretive structural modeling approach. *Frontiers in Built Environment*, *8*, 864814.

Labour Research Service. (2020). Sector Report: Construction. Retrieved from https://www.lrs.org.za/wp-content/uploads/2021/03/Construction-2019-Sector-Report-.pdf

Ngqentsu, M. B. (2023). Investigating the challenges working-class women face in the construction industry-RSA.

Le, Q. T., Pedro, A., & Park, C. S. (2015). A social virtual reality-based construction safety education system for experiential learning. *Journal of Intelligent & Robotic Systems*, *79*, 487-506.

Li, H., Chan, G., & Skitmore, M. (2013). Integrating real time positioning systems to improve blind lifting and loading crane operations. *Construction Management and Economics*, *31*(6), 596-605.

Li, Y., & Liu, C. (2019). Applications of multirotor drone technologies in construction management. *International Journal of Construction Management*, *19*(5), 401-412.

Li, X., Yi, W., Chi, H. L., Wang, X., & Chan, A. P. (2018). A critical review of virtual and augmented reality (VR/AR) applications in construction safety. *Automation in Construction*, *86*, 150-162.

Liu, T., Gong, G. F., Yang, H. Y., Chen, Y. X., & Zhu, Y. (2019). Trajectory control of tunnel boring machine based on adaptive rectification trajectory planning and multi-cylinders coordinated control. *International Journal of Precision Engineering and Manufacturing*, *20*(10), 1721-1733.

Llale, J., Setati, M., Mavund, S., Ndlovu, T., Root, D., & Wembe, P. CONSTRUCTION STAKEHOLDERS'PERCEPTIONS ON THE WIDER ADOPTION OF CONSTRUCTION AUTOMATION AND ROBOTICS: AN EXPLORATORY PRE-STUDY. In *THIRTY-FIFTH ANNUAL CONFERENCE* (p. 567).

Llale, J., Setati, M., Mavunda, S., Ndlovu, T., Root, D., & Wembe, P. (2020). A review of the advantages and disadvantages of the use of automation and robotics in the construction industry. In *The Construction Industry in the Fourth Industrial Revolution: Proceedings of 11th Construction Industry Development*

Board (CIDB) Postgraduate Research Conference 11 (pp. 197-204). Springer International Publishing.

Lucas, J. (2020). Rapid development of Virtual Reality based construction sequence simulations: a case study. *J. Inf. Technol. Constr.*, *25*, 72-86.

Lu, W., Chen, K., Xue, F., & Pan, W. (2018). Searching for an optimal level of prefabrication in construction: An analytical framework. *Journal of Cleaner Production, 201*, 236-245. doi:https://doi.org/10.1016/j.jclepro.2018.07.319

Oke, A., Akinradewo, O., Aigbavboa, C., & Akinradewo, O. (2019, November). *Benefits of construction automation and robotics in the South African construction industry*. In *IOP Conference Series: Earth and Environmental Science* (Vol. 385, No. 1, p. 012063). IOP Publishing.

Omar, T., & Nehdi, M. L. (2016). Data acquisition technologies for construction progress tracking. *Automation in Construction*, *70*, 143-155.

Parvinen, P., Hamari, J., & Pöyry, E. (2019). Introduction to the Minitrack on Mixed, Augmented and Virtual Reality: Co-designed Services and Applications.

Pedro, A., Le, Q. T., & Park, C. S. (2016). Framework for integrating safety into construction methods education through interactive virtual reality. *Journal of professional issues in engineering education and practice*, *142*(2), 04015011.

Peel, H., Luo, S., Cohn, A. G., & Fuentes, R. (2018). Localisation of a mobile robot for bridge bearing inspection. *Automation in Construction*, *94*, 244-256

Poppy, W. (1994). Driving forces and status of automation and robotics in construction in Europe. *Automation in construction*, *2*(4), 281-289.

PricewaterhouseCoopers. (2015). Will robots really steal our jobs? Retrieved from https://www.pwc.co.uk/economic-services/assets/international-impact-of-automation-feb-2018.pdf

Proverbs, D. G., Holt, G. D., & Olomolaiye, P. O. (1999). Productivity rates and construction methods for high rise concrete construction: a comparative evaluation of UK, German and French contractors. *Construction Management & Economics*, *17*(1), 45-52.

Pradhananga, P., ElZomor, M., & Santi Kasabdji, G. (2021). Identifying the challenges to adopting robotics in the US construction industry. *Journal of Construction Engineering and Management*, *147*(5), 05021003.

Rakha, T., & Gorodetsky, A. (2018). Review of Unmanned Aerial System (UAS) applications in the built environment: Towards automated building inspection procedures using drones. *Automation in Construction*, *93*, 252-264.

Rahman, M. R. U., Khatib, M. I., Seema Rani, P., Shaikh, S., & Gunashekar, G. (2019). Effect of computer aided drafting on manual drafting skills. *International Journal of Innovative Technology and Exploring Engineering*, *8*(11), 3012-3014.

Robinson, L. (2009). A summary of diffusion of innovations.

Ruggiero, A., Salvo, S., & St Laurent, C. (2016). Robotics in construction. *Worcester Polytechnic Institute*.

Rutberg, S., & Bouikidis, C. D. (2018). Focusing on the fundamentals: A simplistic differentiation between qualitative and quantitative research. *Nephrology Nursing Journal*, *45*(2), 209-213.

Sacks, R., Perlman, A., & Barak, R. (2013). Construction safety training using immersive virtual reality. *Construction Management and Economics*, *31*(9), 1005-1017.

Sahin, I. (2006). Detailed review of Rogers' diffusion of innovations theory and educational technology-related studies based on Rogers' theory. *Turkish Online Journal of Educational Technology-TOJET*, *5*(2), 14-23.

Sartipi, F. (2020). Diffusion of innovation theory in the realm of environmental construction. *Journal of Construction Materials*, *1*(4), 2-4.

Seliger, G. (1988). Rules for expanding robot applications. *Robotics and computer-integrated manufacturing*, *4*(1-2), 187-196.

SIMINIALAYI, L. I., & FOMSI, E. F. (2023). IMPACT OF COMPUTER-AIDED DESIGN AND DRAFTING ON STUDENTS'ATTITUDE AND PERFORMANCE IN TECHNICAL DRAWING IN UNITY COLLEGES IN PORT HARCOURT. *EPRA International Journal of Multidisciplinary Research (IJMR)*, *9*(2), 318-325.

Skibniewski, M. J. (1992, June). Current status of construction automation and robotics in the United States of America. In *9th International Symposium on Automation and Robotics in Construction* (pp. 17-24).

Smallwood, J. J. (2007, June). The nature and contents of health and safety (H&S) specifications. In *Proceedings of the 2nd Built Environment Conference* (pp. 17-19).

Saunders, M., Lewis, P., & Thornhill, A. (2019). *Research methods for business students*. Pearson education.

Scotland, J. (2012). Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. English language teaching, 5(9), 9-16.

Soiferman, L. K. (2010). Compare and Contrast Inductive and Deductive Research Approaches. *Online Submission*.

Sithole, N. G. (2016). *An examination of soccer fans' social media usage to access news about Premier Soccer League matches in the Capricorn District of Limpopo province* (Master's thesis, University of Limpopo).

Shamsuddin, S., Yussof, H., Ismail, L. I., Mohamed, S., Hanapiah, F. A., & Zahari, N. I. (2012). Initial response in HRI-a case study on evaluation of child with autism spectrum disorders interacting with a humanoid robot Nao. *Procedia Engineering*, *41*, 1448-1455.

Smith, D. (2012). Printed buildings: an international race for the ultimate in automation. *Construction Research and Innovation*, *3*(2), 26-31.

Stojanovska-Georgievska, L., Sandeva, I., Krleski, A., Spasevska, H., Ginovska, M., Panchevski, I., ... & Funtik, T. (2022). BIM in the Center of Digital Transformation of the Construction Sector—The Status of BIM Adoption in North Macedonia. *Buildings*, *12*(2), 218.

Statistics South Africa. (2022). Census 2022 statistical release.

Symon, G., & Cassell, C. (Eds.). (2012). *Qualitative organizational research: core methods and current challenges*. Sage.

Talukder, M. (2012). Factors affecting the adoption of technological innovation by individual employees: An Australian study. *Procedia-Social and Behavioral Sciences*, *40*, 52-57.

Taherdoost, H. (2016). Sampling methods in research methodology; how to choose a sampling technique for research. *How to Choose a Sampling Technique for Research (April 10, 2016)*.

Tam, W. Y., Tam C. M., Chan, K. W. & Ng, C. Y. (2006) Cutting Construction Wastes by Prefabrication, International Journal of Construction Management, 6:1, 15-25, DOI: 10.1080/15623599.2006.10773079

Tangkar, M., & Arditi, D. (2000). Innovation in the construction industry. *Civil Engineering Dimension*, *2*(2), 96-103.

Tatum, C. B. (1984). What prompts construction innovation?. *Journal of construction engineering and management*, *110*(3), 311-323.

M Tehrani, B., BuHamdan, S., & Alwisy, A. (2022). Robotics in assembly-based industrialized construction: a narrative review and a look forward. *International Journal of Intelligent Robotics and Applications*, 1-19.

Tubane, N. (2017). *Determinants of the performance of construction SMEs in South Africa* (Doctoral dissertation).

Tucker, R. (1988). High payoff areas for automation applications. In *Proceeding, 5th International Symposium on Automation and Robotics in Construction, Japan Industrial Robot Association, Tokyo* (pp. 9-16).

Turk, Ž. (2016). Ten questions concerning building information modelling. *Building and Environment*, *107*, 274-284.

Vähä, P., Heikkilä, T., Kilpeläinen, P., Järviluoma, M., & Gambao, E. (2013). Extending automation of building construction—Survey on potential sensor technologies and robotic applications. *Automation in construction*, *36*, 168-178.

Valero, E., Adán, A., & Cerrada, C. (2015). Evolution of RFID applications in construction: A literature review. *Sensors*, *15*(7), 15988-16008

Ullah, K., Lill, I., & Witt, E. (2019, May). An overview of BIM adoption in the construction industry: Benefits and barriers. In *10th Nordic Conference on Construction Economics and Organization*. Emerald Publishing Limited.

Wang, P., Wu, P., Wang, J., Chi, H. L., & Wang, X. (2018). A critical review of the use of virtual reality in construction engineering education and training. *International journal of environmental research and public health*, *15*(6), 1204.

Wani, T. A., & Ali, S. W. (2015). Innovation diffusion theory. *Journal of general management research*, *3*(2), 101-118.

Wu, P., Zhao, X., Baller, J. H., & Wang, X. (2018). Developing a conceptual framework to improve the implementation of 3D printing technology in the construction industry. *Architectural science review*, *61*(3), 133-142.

Yagi, J., Arai, E., & Arai, T. (2005). Parts and packets unification radio frequency identification (RFID) application for construction. *Automation in construction*, *14*(4), 477-490.

Yan, R. J., Kayacan, E., Chen, I. M., Tiong, L. K., & Wu, J. (2018). QuicaBot: Quality inspection and assessment robot. *IEEE Transactions on Automation Science and Engineering*, *16*(2), 506-517.

Yates, K., Sapountzis, S., Lou, E., & Kagioglou, M. (2009, June). BeReal: Tools and methods for implementing benefits realisation and management. In *5th Nordic Conference on Construction Economics and Organisation. Reykjavík* (pp. 223-232).

Yin, J., Chen, D., & Li, Y. (2016). Smart train operation algorithms based on expert knowledge and ensemble CART for the electric locomotive. *Knowledge-Based Systems*, *92*, 78-91.

Zalaghi, H., & Khazaei, M. (2016). The role of deductive and inductive reasoning in accounting research and standard setting. *Asian Journal of Finance & Accounting*, *8*(1), 23-37.

Zhang, M., Cao, T., & Zhao, X. (2017). Applying sensor-based technology to improve construction safety management. *Sensors*, *17*(8), 1841.

Zuk, W. (1985). *Final report, robotics in construction* (No. VHTRC 85-R38). Virginia Transportation Research Council.

APPENDICE 1: COVERING LETTER

Construction Automation & Robotics

Dear Sir / Madam,

My name is Kurisani Mbhalati. I am a Masters in Business Administration student at the University of the Witwatersrand, Johannesburg. As part of my studies, I have to undertake a research project. I am investigating the topic *Construction Professionals' Awareness of Construction Automation and Robotics in South Africa* under the supervision of Dr Jenika Gobind. The aim of the research project is to find out to what extent, if any, are construction professionals aware and familiar with the applications of robotics and automation in the construction industry.

As part of this project, I would like to invite you to take part in answering a questionnaire. This will involve answering multiple choice questions and will take around 10 minutes.

There will be no personal costs to you if you participate in this project. You will not receive any direct benefits from participation. You may withdraw at any time or not answer any question if you do not want to. The questionnaire will be completely confidential and anonymous as I will not be asking for your name or any identifying information. The information you give to me will be held securely and not disclosed to anyone else.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za

Yours sincerely,

Kurisani Mbhalati

078 188 1720 | kurisanimbhalati@gmail.com

APPENDICE 2: RESEARCH SURVEY

SECTION A - BACKGROUND INFORMATION

This section of the questionnaire refers to background or biographical information. Although I am aware of the sensitivity of the questions in this section, the information will allow me to compare groups of respondents. Once again, I assure you that your responses will remain anonymous. Your cooperation is appreciated.

---

1. **1. Gender** *

   Mark only one oval.

   ( ) Male
   ( ) Female

2. **2. How old are you? (years)** *

   ____

3. **3. State your highest educational qualification** *

   Mark only one oval.

   ( ) No qualification
   ( ) Matric / Grade 12
   ( ) Diploma
   ( ) Degree
   ( ) Honours
   ( ) Masters
   ( ) Doctorate

4. **4. What is your professional designation?** *

Mark only one oval.

- Architect
- Surveyor
- Technician
- Technologist
- Engineer
- Project manager
- Construction manager
- Foreman
- Contracts manager
- Other: ____________________

5. **5. How many years of experience do you have in the construction industry?** *

Mark only one oval.

- 1 - 5 years
- 6 - 10 years
- 11 - 15 years
- 16 - 20 years
- 20 years and above

6. **6. State the type of institution that you currently work for** *

Mark only one oval.

- Private client
- Consultant
- Contractor
- Government

SECTION B - AWARENESS OF TYPES OF ROBOTICS AND CONSTRUCTION AUTOMATION

This section explores the levels of awareness of robotics and construction automation. Please indicate your answers using the 5-point scale.

7. **7. What is your level of awareness of the following types of robotics and construction automation?**

Mark only one oval per row.

	Very low	Low	Average	High	Very high
Sensing technologies (sensors, lasers, cameras etc.)	◯	◯	◯	◯	◯
3D printing	◯	◯	◯	◯	◯
Virtual reality	◯	◯	◯	◯	◯
Autonomous vehicles	◯	◯	◯	◯	◯
Drones	◯	◯	◯	◯	◯
Robotic arms	◯	◯	◯	◯	◯
Building information modelling (BIM)	◯	◯	◯	◯	◯
Computer-aided design (CAD)	◯	◯	◯	◯	◯
Global positioning system (GPS)	◯	◯	◯	◯	◯
Prefabrication / Off-site construction	◯	◯	◯	◯	◯

SECTION C - BENEFITS OF ADOPTING ROBOTICS AND CONSTRUCTION AUTOMATION

This section explores the perceived benefits of adopting robotics and construction automation in the construction industry. Please indicate your answers using the 5-point scale.

8. **8. To what extent do robotics and construction automation yield the following benefits for the construction industry?**

Mark only one oval per row.

	Very low	Low	Average	High	Very high
Occupational safety improvements	◯	◯	◯	◯	◯
Higher quality and accuracy	◯	◯	◯	◯	◯
Increased productivity	◯	◯	◯	◯	◯
Reduced material disposal	◯	◯	◯	◯	◯
Cost reduction	◯	◯	◯	◯	◯
Time saving	◯	◯	◯	◯	◯
Less human labour	◯	◯	◯	◯	◯

SECTION D - BARRIERS TO ADOPTING ROBOTICS AND CONSTRUCTION AUTOMATION

This section of the questionnaire aims to determine the barriers to adopting robotics and construction automation in the construction industry. Please indicate your answers using the 5-point scale.

9. **9. To what extent do you agree that the following items act as barriers to adopting robotics and construction automation?**

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
High costs of acquiring technologies	⬭	⬭	⬭	⬭	⬭
Unavailable locally	⬭	⬭	⬭	⬭	⬭
Difficult to use and not easily understood	⬭	⬭	⬭	⬭	⬭
Incompatible with current construction practices	⬭	⬭	⬭	⬭	⬭
Maintenance costs	⬭	⬭	⬭	⬭	⬭
Low awareness of the technologies	⬭	⬭	⬭	⬭	⬭
Resistance to change by the construction industry	⬭	⬭	⬭	⬭	⬭
Legal issues and insufficient governmental support	⬭	⬭	⬭	⬭	⬭

APPENDICE 3: ETHICAL CLEARENCE

Graduate School of Business Administration
University of the Witwatersrand, Johannesburg

Wits Business School Ethics Committee
Constituted under the University Human Research Ethics Committee (Non-Medical)

Ethics Clearance Certificate

Ethics protocol number: WBS/BA1636189/600

This certificate is only valid with a legitimate ethics protocol number and signed by the Researcher (below).

Project title	Construction professionals' awareness of automation and robotics in South Africa
Investigator / Researcher	Mr Kurisani Mbhalati
Nature of Project	MBA (Research Article)
Decision of the Committee	Approved, provided stakeholders and participants are guaranteed confidentialty.
Issue Date of Certificate	2022-10-05
Expiry date	Date of submission of the project / research report
Chairperson	Prof Anthony Stacey ☎ +27 11 717 3587 +27 82 880 4531 anthony.stacey@wits.ac.za

Declaration by Researcher

One copy must be signed by the Researcher and returned to the Chairperson of the Wits Business School Ethics Committee.

I fully understand the conditions under which I am authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I undertake to resubmit the protocol to the Committee.

Signature | Date: 24/10/2022