EVALUATING THE IMPACT OF INNOVATIVE TECHNOLOGIES ON THE DELIVERY AND AFFORDABILITY OF SOUTH AFRICAN AFFORDABLE HOUSING

By

Jeffrey Jr. Mahachi

This research is submitted towards the fulfilment of the requirements for the Degree of Master of Philosophy in Construction Economics and Management

Department of Construction Economics and Management Faculty of Engineering and the Built Environment University of Cape Town

Supervisors:

Dr Kathy Michell

Dr Alireza Moghayedi

August 2023

ACKNOWLEDGEMENT

I want to extend a heart of gratitude and thankfulness to my supervisor Dr. Alireza Moghayedi for his assistance and patience through this journey. With his help and assistance from my father Prof. Jeffrey Mahachi, I was opened to many opportunities throughout this journey which really helped to make this season of my life memorable. I would also like to thank Prof. Kathy Michell for graciously proofreading my paper to ensure the best possible version is submitted. However, I cannot end without thanking and acknowledging the loved ones in my life, from my loving family, supportive girlfriend, and caring friends. The biggest thing in this process that I learned is that if you want to go fast, go alone, but if you want to go far, then do it together. And in this season, I chose the latter. I thank God and praise him for this opportunity and I am excited for the next journey which lies ahead.

"You got to know when to hold them, know when to fold them, know when to walk away and know when to run. You never count your money when you're sitting at the table. There'll be time enough for counting when the dealing's done."

PLAGIARISM DECLARATION

Name: Jeffrey Jr. Mahachi
Student Number: Course: MHCJEF001

Master of Philosophy in Construction of Economics and Management

I know the meaning of plagiarism and declare that all the work in the document, save for the properly acknowledged, is my own. This dissertation has been submitted to the Turnitin module (or equivalent similar and originality checking software) and I confirm that my supervisor has seen my report and that any concerns revealed by such have been resolved with my supervisor.

I have not allowed, and will not allow anyone, to copy my work with the intention of passing it off as his or her work.

Signature: Signed by candidate

Abstract

The present study aimed to evaluate the impact of innovative technologies on the delivery and affordability of low-income housing in South Africa. Given the rising demand for affordable housing due to a growing population and urbanisation, the study aimed to investigate the role of new technologies in enhancing housing delivery. The study explored the use of various innovative technologies such as Unmanned Aerial Vehicles (UAVs), Building Information Modelling (BIM), Geographic Information Systems (GIS), 3D Printing, Virtual Reality (VR), Augmented Reality (AR), Artificial Intelligence (AI), Smart Sensors, Modular and Prefabrication, Object-Oriented Programming (OOP), and Project Portfolio Management (PPM) as potential solutions. The research adopted a mixed-method approach, combining qualitative and quantitative methods. The target population included home developers, experts, policymakers, and academics involved in affordable housing development. Qualitative data were gathered through expert interviews until saturation was achieved, while quantitative data was obtained from 100 survey questions filled out by experts involved with affordable housing in South Africa. The data analysis method consisted of thematic analysis and descriptive and inferential statistics. The results of the study indicated that these innovative technologies have the potential to not only accelerate the delivery of affordable housing but also make it more cost-efficient. The analysis showed that 3D printing, modular and prefabrication were three technologies that could significantly increase housing delivery, while BIM, GIS, VR, OOP, and PPM could efficiently aid in the planning of affordable housing, reducing design conflicts, improving project schedules, and cutting development costs. Smart Sensors, AR, and UAVs could indirectly enhance housing delivery by monitoring construction, ensuring the site is built on schedule and correctly, and monitoring construction worker productivity. However, the study also identified high costs and limited social acceptance as major challenges. To address these issues, the study emphasised the need for the government to promote the adoption and implementation of these technologies through financial incentives and subsidies for companies that adopt them, as well as investment in research and development. The study also stressed the importance of promoting the use of these technologies in high-end housing developments in addition to affordable housing projects. In conclusion, the results of this study highlight the significance of considering innovative technologies in the delivery of affordable housing in South Africa. The findings suggest that the government has a critical role to play in promoting the adoption and implementation of these technologies through financial incentives and investment in research and development, helping to overcome current challenges and making affordable housing a reality for all.

Table of Contents

List of Tables

List of Figures

CHAPTER ONE: GENERAL INTRODUCTION

1.1 Introduction

Developing nations similar to South Africa often struggle with rapid urbanisation as they develop. In South Africa, urbanisation increased from 62.22% in 2010 to 67.35% in 2020 (Statista, 2021). This often leads to higher demand for housing, particularly affordable housing. However, the supply of affordable housing can often take a long time to meet this demand, leading to a lack of equilibrium between supply and demand. The negative impacts of urbanisation on the housing sector in South Africa, as well as the limitations on innovation in the construction industry (Yusof, et al., 2014), highlight the importance of finding new solutions to improve housing delivery and affordability. One potential solution is to adopt innovative design and construction methods that streamline workflow and reduce miscommunications and mismanagement between design and construction teams (Shahparvari, et al., 2019). This could involve the use of innovative technologies, such as 3D printing or modular construction, or the implementation of new project management techniques, such as agile methodologies. By exploring and implementing these types of solutions, it may be possible to address the challenges of urbanisation and improve the housing sector in South Africa. To understand the full extent of these challenges, it is essential to delve into the broader context of South Africa's urbanization and its impact on the housing sector.

1.2 Background of Study

South Africa has high rates of urbanisation, particularly due to its fast-growing economy and high GDP, which makes it the third wealthiest country in Africa (World Population Review, 2021). This contributes to the rising urbanisation rates as households move from rural living to middle-income households and livelihoods. However, rising urbanisation rates also lead to rising demand for affordable housing. With affordable housing in high demand, the affordable housing sector still has prolonged periods for the delivery of affordable houses, causing an imbalance between housing demand and supply. According to several sources, it is not uncommon for households to experience prolonged waiting periods for the construction and delivery of affordable housing. In South Africa, for instance, it has been reported that households may wait over five years to deliver their homes. In such cases, the households may have applied for affordable housing and construction may have commenced, but despite the passage of five years, their promised dwelling remains incomplete and lacking windows, doors, ceilings, paint, and basic infrastructure such as electricity and plumbing. Furthermore, for this same household, the roof tiles had started falling off, rendering the house unliveable (Ntongana, 2016). These prolonged delivery periods are often caused by various issues that may occur during the different stages of the housing delivery process. Studies indicate that most delays in affordable housing delivery tend to be due to insufficient funds to finance the project to completion, changes in designs and drawings, ineffective communication among parties involved, slow decision-making (due to zoning, building permits, etc.) and contractors insolvency (Owolabi, et al., 2014).

In an economy that is rapidly digitalising, industries that do not adopt evolving technological trends tend to suffer in terms of product delivery. In most cases, the adoption of technologies designed to improve workflow and efficiencies helps industries improve their production level. However, developing countries such as South Africa tend to lag in the implementation of technologies, especially within the housing sector (Bui, et al., 2016). The lack of technological adoption in the industry has caused a lack of digitalisation, ultimately causing major inefficiencies in housing delivery and leaving lower-class households suffering from the

negative effects of the industry's resistance to change (Shahparvari, et al., 2019). Adopting innovative systems and technologies within the construction industry can be a slow process due to the industry being heavily regulated and involving many actors who each play a part (Yusof, et al., 2014). The South African housing sector, which is part of the construction industry, faces issues with design and development efficiencies. However, even if such innovations are approved, for example, Unmanned Aerial Vehicles (UAVs) and Building Information Modelling (BIM), there are still professionals who choose to stick with traditional methods due to the industry's culture of resistance to change (Shahparvari, et al., 2019). For example, most professionals in the affordable housing sector still prefer to use hard copies to record and interpret data, although some industry professionals use digital formats for their projects, the majority still rely on outdated methods due to their cultural resistance to change in the construction industry and a lack of resources to invest in new technologies (Shahparvari, et al., 2019). To address these issues and improve the housing delivery process in South Africa, it is important to find ways to overcome the barriers to technology adoption and innovation in the construction industry. This could involve providing training and resources to help professionals learn and adapt to new technologies, as well as implementing policies and incentives to encourage the adoption of innovative solutions. It may also be helpful to engage with private sector companies or organisations that have expertise in innovative housing solutions and can provide guidance and support for the adoption of new technologies. By taking these steps, it may be possible to improve the efficiency of the housing delivery process in South Africa and ensure that affordable housing is more widely available to meet the needs of its growing population. These challenges underscore the pressing need to understand and address the root causes of inefficiencies in housing delivery, which will be detailed in the following problem statement.

1.3 Problem Statement

Rapid urbanization in South Africa, fueled by its status as the third wealthiest country in Africa (World Population Review, 2021), has precipitated a critical demand for affordable housing. This demand is compounded by protracted housing delivery timelines, where households frequently endure waits exceeding five years only to receive homes that are incomplete or uninhabitable, lacking essentials such as windows, doors, and basic utilities (Ntongana, 2016). The underlying causes of these delays include not only funding shortages, changes in design plans, and ineffective communication among stakeholders but also protracted bureaucratic processes related to zoning and permit approvals, and contractor insolvency (Owolabi, et al., 2014). Moreover, the persistence of informal settlements highlights the inadequacy of current housing policies and their implementation. These settlements, often lacking legal recognition and basic public services, underscore the government's failure to manage urban growth effectively and to provide viable housing solutions for the burgeoning urban population. According to the Centre for Affordable Housing Finance in Africa (2023), the urban housing backlog stands at about 2.4 million houses, growing at a rate of 178,000 units per year (CAHF, 2023). Furthermore, the construction industry’s reluctance to embrace innovative technologies such as Unmanned Aerial Vehicles (UAVs) and Building Information Modelling (BIM) exacerbates these issues. Despite the potential of these technologies to improve efficiency and reduce costs, there is significant resistance within the industry, rooted in traditional practices and a lack of investment in new technologies (Shahparvari, et al., 2019). Addressing these multifaceted problems requires a critical examination of government policies and a concerted effort to overcome cultural and resource-based barriers to technological adoption. By fostering a more innovative approach within the housing sector, South Africa can begin to close the gap between housing demand and supply, ultimately reducing the prevalence of informal

settlements and improving the lives of its urban residents. To further explore and address these complex issues, the following research questions were formulated.

1.4 Research Questions

The main research question which was determined and answered through the development of the research is:

What are the impacts of innovative technologies on the delivery process and affordability of South African affordable housing?

To address the main research question, answers are sought to the following specific sub-questions:
SQ1: What are the various issues facing the delivery of affordable housing within South Africa?
SQ2: What are the innovative technologies that can be used in the process of design and construction of South African affordable housing?
SQ3: What is the level of adoption of innovative technologies within the South African affordable housing design and construction process?
SQ4: What are the pros and cons of using innovative technologies within the South African affordable housing development?
SQ5: What are the challenges and barriers that arise with the adoption of innovative cyber technologies within South African affordable housing projects?

1.5 Research Aim

The goal of this research is to examine the influence of innovative technologies on the delivery process of South African affordable housing and determine whether they can accelerate the delivery of affordable housing and ensure its affordability.

1.6 Research Objectives

The research objectives are to:

- Identify the issues facing the delivery of affordable housing within South Africa.
- Examine various innovative technologies that can be used to design and construct affordable housing.
- Determine the level of adoption of innovative technologies within South African affordable housing development.
- Determine the challenges and barriers to the adoption of innovative cyber technologies within South African affordable housing projects.
- Examine the advantages and disadvantages of innovative technologies in South African affordable housing.
- Evaluating the impact that innovative technologies have on the delivery process and affordability of South African affordable housing.

1.7 Hypothesis

The present study aims to investigate the impact of the utilisation and usage of innovative technologies on the delivery and affordability of affordable housing in South Africa. The following hypotheses have been formulated based on the research objectives:

Hypothesis 1:

The utilisation of innovative technologies in affordable housing design and construction has a significant impact on the affordable housing delivery process.

- Null Hypothesis (H0): There is no significant impact of the utilisation of innovative technologies on the perceived efficiency of the delivery process in affordable housing projects.
- Alternative Hypothesis (H1): There is a significant impact of the utilisation of innovative technologies on the perceived efficiency of the delivery process in affordable housing.

Hypothesis 2:

The level of usage of innovative technologies has a significant impact on the affordability of affordable housing projects.

- H0: There is no significant impact of the level of usage of innovative technologies on the affordability of affordable housing projects.
- H1: There is a significant impact of the level of usage of innovative technologies on the affordability of affordable housing projects.

1.8 Methodology

The combination of a quantitative and qualitative approach for data collection was deemed the most appropriate method for conducting the research for this study. This mixed-method approach formed the basis of many of the necessary aspects needed to complete the methodology. The research philosophy favoured a pragmatist approach, as this seemed the best fit for the usage of both quantitative and qualitative data collection methods. Thereafter, a realistic research philosophy was adopted as the research paradigm to complement the chosen research philosophy. When defining the target population, it was deemed appropriate to focus solely on home developers, policymakers, and academics involved in affordable housing. The sample size for the targeted population was determined based on the guidelines set for the qualitative and quantitative data. For the qualitative data, various intimate interviews were conducted until the saturation point was reached. For the quantitative data, numerous online surveys were sent and completed by the targeted population. In summary, the data was collected through a literature review, one-on-one expert interviews, and online surveys. Before beginning data analysis, a unit of analysis was formed based on the opinions of experts, academics, and policymakers. Finally, the data was analysed using thematic analysis, t-tests, and hypothesis testing. While the chosen methodology provides a robust framework for this research, it is important to acknowledge certain limitations and delimitations that may impact the findings.

1.9 Limitations and Delimitations

1.9.1 Limitations:

The research encountered several limitations that impacted data collection and the generalisability of findings. The onset of the COVID-19 pandemic required a shift to online interviews instead of in-person interactions with stakeholders. Additionally, limited access to databases led to a longer data collection process as contact details had to be obtained through alternative means. The introduction of the Protection of Personal Information Act (POPI Act)

further complicated obtaining professionals' information. Despite these challenges, the study contributes valuable insights into the affordable housing crisis in South Africa. However, it is important to acknowledge that the study's sample size of home developers and experts may limit the generalisability of the findings. The self-reported nature of survey responses also introduces potential biases or measurement errors. The study did not delve into the cultural and social factors influencing the adoption of innovative technologies in the affordable housing sector. Despite these limitations, the research underscores the potential of innovative technologies to improve affordability and delivery in affordable housing, emphasising the need to address barriers such as high adoption costs, limited technical knowledge, and social acceptance.

1.9.2 Delimitations:

This research project employed specific delimitations to ensure focused and relevant data collection. The delimitations encompassed the following aspects: Firstly, the scope of the study was restricted to affordable housing within the context of South Africa, enabling a concentrated analysis of the country's specific affordable housing sector. Secondly, the professionals interviewed or surveyed were required to possess experience in the South African affordable housing industry, ensuring insights directly relevant to the context. Thirdly, the study exclusively considered affordable housing types that were certified by the National Home Builders Registration Council (NHBRC), ensuring a standardised assessment. Lastly, the proposed innovative technologies had to be feasible for implementation within the housing development process, aligning with practical considerations. These delimitations were instrumental in streamlining the research to address specific objectives within the defined parameters.

With an understanding of the study's limitations and delimitations, the following outlines the structure of this thesis to provide a comprehensive overview of the research.

1.10 Structure of Thesis

This thesis will be structured as follows:

- Chapter 1: Introduction - This chapter provides an overview of the project, including the aim, objectives, and research questions.
- Chapter 2: Review of Literature - This chapter presents a review of the relevant literature on rapid population and urbanisation growth, affordable housing issues in South Africa, and the adoption of innovative technologies within the affordable housing sector and construction industry. The literature review is based on scholarly journal articles and reputable web sources gathered and analysed for this study.
- Chapter 3: Research Methodology - This chapter describes the methods and techniques used to collect and analyse the data for this study, including the research philosophy, research paradigm, research approach, target population, and methods of data collection.
- Chapter 4: Presentation of Findings - This chapter presents the findings of the research, including both qualitative and quantitative data. The data is presented in a way that highlights common trends and patterns.
- Chapter 5: Conclusion - This chapter summarises the key findings and implications of the research and provide recommendations for future research in the field.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter aims to thoroughly review various research publications, resources, and journals related to the research topic. It begins by examining the causes of urbanisation and population growth patterns in South Africa, and how these growth patterns may impact the South African economy and society. It then investigates the concept of affordable housing in South Africa, which has subjective and varying definitions. A detailed examination of the affordable housing supply chain is conducted to understand the various hindrances to the delivery of affordable housing that have contributed to the backlog. The chapter also analyses innovative technologies that may improve the effective delivery of South African affordable housing and concludes with a summary of the key findings from the literature review.

2.2 Overall Position of South African Affordable Housing

The provision of suitable housing and living conditions is not only a constitutional requirement in the Republic of South Africa under Section 26 but also a global obligation established by the United Nations (UN). However, the global challenge of delivering affordable housing has intensified due to rapid population growth and urbanisation. In the context of South Africa, which boasts one of the highest urbanisation rates in Africa (68% compared to the regional average of 44%), the country has struggled to keep up with the demand for adequate urban infrastructure following the apartheid era. Consequently, a significant backlog in affordable housing delivery has emerged (Moghayedi, et al., 2023). This mounting backlog is a key driver behind the proliferation of informal housing settlements, commonly known as slums, in urban areas worldwide. In addition, Africa is experiencing a triple process of rapid population growth, high urbanisation, and digital transformation, moving from a rural majority to an urban majority (Benna & Garba, 2016). The extended duration of affordable housing projects often forces households to reside in slum-like settlements while awaiting completion, leading to the spread of diseases due to inadequate sanitation, overcrowding, and lack of cleanliness (Bodo, 2019). This highlights the current lack of basic necessities in South African townships to meet the residents' essential needs. Moreover, studies emphasise the detrimental effects of poverty-stricken households, substandard housing conditions, and unsafe neighbourhood facilities on the overall quality of life and well-being of individuals and families in these townships (Moghayedi, et al., 2023). These findings underscore the significance of not only household socioeconomic characteristics but also the condition of the neighbourhoods, including factors such as safety, security, and access to essential services and amenities such as proper shelter, clean water, and electricity. Consequently, the neighbourhood conditions in South African townships are severely inadequate, leading to low overall well-being within these communities. Estimations in 2019 suggested that an additional capital of R800 billion (approximately US $53.3 billion) would be required to eliminate the backlog in affordable housing by 2020. However, the backlog continues to grow, indicating the persistent challenges in addressing the affordable housing shortage (Bodo, 2019). Scholars argue that innovative technologies and practices can contribute to the successful delivery of affordable housing (Bennett, et al., 2019). These technologies and practices aim to improve operational challenges, workflows, and efficiencies within the context of an affordable housing project while promoting process innovation (Martinez, et al., 2019). Research from Shahparvari et al. (2019) agrees with this notion and suggests that prolonged construction periods, miscommunication and mismanagement between the design and construction teams, and rework in construction due to

a subpar supply chain are major factors that hinder the efficient delivery of affordable housing. These issues can be addressed and resolved with innovative strategies, such as the adoption of technologies (Shahparvari, et al., 2019). To overcome the affordable housing crisis in South Africa, it is crucial to consider and implement such innovative solutions. This can help ensure that the legal mandate of appropriate accommodation is met and that all individuals have access to affordable and suitable housing.

2.3 Urbanisation and Population Growth Patterns within South Africa

2.3.1 South Africa's Population Growth

Taking into consideration South Africa, a nation with a steady population growth rate of 1.28% per year, the nation has increased its population by 20 million citizens between the period of 1994 and 2021, thus a current population of just over 60 million (World Population Review, 2021). Taking the steady growth rate into account, by the year 2050, the South African population should rise to just over 81 million people. According to the United Nations (UN), a large portion of these people will be living in slums in the coming years due to the failure to address housing issues in Africa as a whole. There remains continued growth of slums and 'poorly serviced informal settlements', with approximately 75 – 99% of urban residents living in slum-like housing in Africa (Carrington, 2015). In South Africa specifically, the statistics surrounding citizens living in informal settlements are particularly concerning. At the time the Statistics (2017) stated that 12.1% of South Africa's population lived in informal housing. When looking at each province specifically, 20.4% of Gauteng's population was living in informal households, 18.5% of North West's population, 15.1% of Western Cape's, 6.5% of Eastern Cape's, and 4.5% of Limpopo's. The same survey identified that within South Africa alone, 1.3 million households had no direct access to piped water. In terms of overall sanitation, 8,242,924 households had flush toilets, 297,847 households used bucket toilets, and 748,597 households had no toilets at all (Statistics, 2017; Manomano, et al., 2017). These statistics highlight the current importance and urgency surrounding the inadequate affordable housing situation in South Africa.

2.3.2 Rapid Urbanisation in South Africa

A clear catalyst for the demand for adequate affordable housing, besides population growth, is rapid urbanisation. Scholars such as Glaeser & Joshi-Ghani (2013) argue that urbanisation has the potential to transform the developing world and that the path to prosperity inevitably runs through the cities (Glaeser & Joshi-Ghani, 2013). However, urbanisation also brings potential threats and challenges to the societies experiencing it. Urbanisation refers to the gradual rise in the urban population, where a growing number of individuals reside in cities or urban areas (Bodo, 2019). Ideally, urbanisation is the process of households moving from rural or informal areas to urban areas in search of higher income or job opportunities with better living standards. In South Africa, this could mean moving from a rural or small-town area to a province like Gauteng or the Western Cape, which is known as rural-urban migration. While this may seem profitable and worthwhile for a household or individual, it can have negative effects on the socio-economic state of both rural and urban areas.

The rate at which South Africa's urban population is growing is alarming. It is estimated that by 2050, 80% of the nation's population will be living in urban areas, which will exacerbate issues with the availability of housing and hinder rural development and growth patterns (Mlambo, 2018). Urbanisation can be caused by a variety of factors, including industrialisation, commercialisation, socially beneficial services, natural increase, and employment opportunities, as identified by Bodo (2019). In most cases, households willingly migrate from their home areas to a new location with the intention of permanent residence, often in search

of better opportunities, technological growth, overall societal advancement, increased economic opportunities, and improved living standards (Bodo, 2019; Mlambo, 2018). While there are factors that attract individuals to urban areas, there are also factors that push people away from their home areas in search of better opportunities. In many rural areas, there is often a lack of basic amenities, little to no government involvement, and no commercial activities, and in some cases, families were forced to live in these areas due to the history of apartheid (Mlambo, 2018; Bodo, 2019). The legacy of apartheid negatively impacted households in South Africa, but since its abolition, previously disadvantaged racial groups now have more freedom and opportunities to migrate to urban areas (Mlambo, 2018).

2.3.3 South Africa's GDP Growth Rate

Nations globally were negatively affected by the ramifications of the Coronavirus Pandemic between 2020 and 2021. To mitigate the spread of the virus, countries implemented social isolation policies that involved closing educational institutions, limiting work, and restricting the mobility of households (Maliszewska, et al., 2020). These measures had a significant and immediate impact on the economies of many countries, leading to a decrease in trade and tourism with partnering economies and a decrease in capital entering various countries (Maliszewska, et al., 2020). South Africa is a clear example of such ramifications. As of June 2022, South Africa's real Gross Domestic Product (GDP) has only just returned to the level it was at before the pandemic (Stats SA, 2022). In Q1 of 2020 (January, February, and March), the nation's Real GDP decreased drastically from R1,148 billion to a plummeting R952 billion in Q2. However, in Q4 of 2020 (October-December), South Africa's real GDP grew by 1.2%. As lockdown restrictions were lifted in 2022, the nation's GDP expanded by 1.9% and the economy slowly recovered, eventually reaching a real GDP of R1,153 billion in Q1 of 2022 (Stats SA, 2022). This brought the nation's overall GDP growth rate for 2021 to 4.9% (Stats SA, 2022). This growth rate shows positive signs for the South African economy, as an ideal growth rate is between 2% and 3%.

Although there were positive numbers in Q4 of 2021, the nation is still recovering from the heavy lockdown restrictions implemented in Q3 of 2021, leading to a slow but steady recovery for the real GDP. As a result, the economy is 1.8% smaller than it was in Q1 of 2020 (Stats SA, 2022). There is light at the end of the tunnel for most industries in South Africa, except for the construction industry, particularly the housing sector. Stats SA (2022) identified that eight of the ten industries in South Africa saw positive results in the first quarter of 2022, during which the national GDP grew to R1 153 billion compared to its 2020 decline of R952 billion (see Figure 2.1). The positive results identified the manufacturing industry as the top performer, while trade, finance, real estate, and business services also made positive turnarounds. On the other hand, the construction and mining sectors recorded negative results with minimal contribution to GDP improvement. Stats SA (2022) highlights the underwhelming results of the construction industry, with the fourth consecutive quarter displaying poor records for residential buildings and construction works. The only turnaround was seen in any economic activity related to non-residential buildings, which increased in the first quarter of 2022.

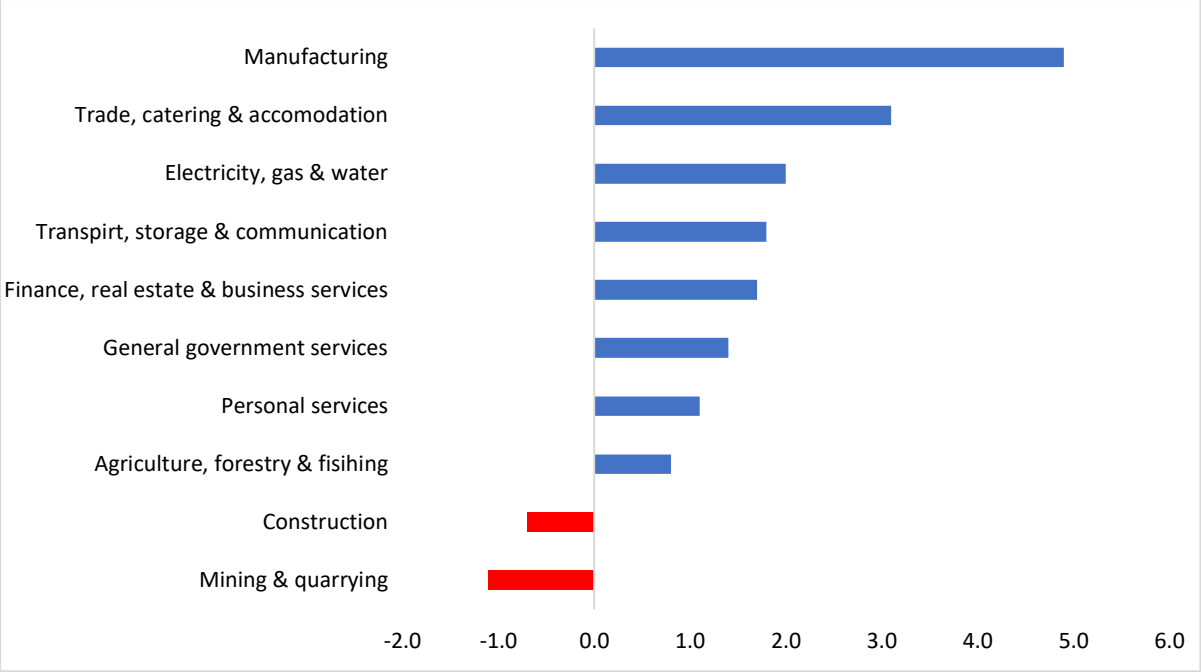


Figure 2.1 Eight of the ten industries recorded a rise in economic activity in the first quarter of 2022 (Stats SA, 2022)

With rising urbanisation, South Africa is not in a financially viable position to handle such growth trends in its current state. The demand for residential living, particularly affordable housing, will not be able to be satisfied due to the negative results recorded in the first quarter of 2022. In addition, the global pandemic has not only contributed to the current state of the construction industry but the industry itself has long been associated with slower adoption rates of efficient strategies and innovative prevention methods to combat poor delivery of affordable housing (Mahachi, 2021).

2.3.4 Positive and Negative Effects of Urbanisation on South Africa's Economy

2.3.4.1 Positive Effects

Urbanisation drives economic development:

Urbanisation is a contributing factor to a growing and stronger economy. As the urban area grows due to rural-to-urban migration, the area will show greater improvement in labour productivity through the methods of sharing, matching, and learning (Sridhar, 2016). Sridhar (2016) argues that big cities that have sprouted from urbanisation can supply more diversified products, as a result, there is an easier chance for citizens to get jobs, and the accumulation of experience is made easier. Furthermore, Zhang (2016) adds that cities have various firms that can respond to market demand changes more effectively, there are fewer transport costs due to the proximity of most trades (ensuring lower costs of trades), and cities have higher tendencies to spark new ideas and innovative practices/technologies due to the high concentration of educated and creative people in one area. In most cases, the calibre of individuals migrating to urban areas is those of higher intellect, future leaders, creatives, or go-getters (Mlambo, 2018). Research shows that within the US, a mere 1% increase in the university-graduate ratio will noticeably increase labour productivity by 0.6%-0.7% and the wage level by 0.6%-1.2% (Sridhar, 2016), imagine the increase when considering developing nations' rapid urbanisation growth rates. As more households gain access to greater opportunities or efforts to further their education in urban areas, it will have a noticeable impact on the overall productivity in these cities. Scholars note that urbanisation is a strong indicator for enhancing productivity growth within economies. There is often a strong correlation between urbanisation and GDP per capita.

The higher the urbanisation level in a country, the higher the GDP per capita; Zhang (2016) argues that no country has moved to a higher-income status without urbanising, and a 70% or higher urbanisation rate is typically used to identify higher-income countries. Although rapid urbanisation may have various side effects, there is no denying that urbanisation leads to the economic growth of cities across the globe. Such growth in cities is the powerhouse that charges the global economy and directs it towards economic growth. Urban cities trump the rate at which rural areas actively contribute to a country's GDP. Research shows that more than 80% of the global GDP is generated by urban cities; the top 100 largest cities contribute 35% of the global GDP, the top 600 cities contribute 62% of the global GDP, the top 1000 cities contribute 68% of the global GDP, and the top 2000 contribute to 75% of the global GDP (Zhang, 2016).

2.3.4.2 Negative Effects

Despite the numerous benefits of urbanisation, such as increased economic growth and access to education and job opportunities, it also brings about negative consequences for the socioeconomic state of urban areas. These negative effects can include inadequate housing and the growth of slums, poverty, poor sanitation, the spread of diseases, waste and pollution, unemployment, and urban crime.

Inadequate Housing and Growth in Slums:

Although urbanisation in South Africa plays an important role in contributing to economic growth, social growth, and rectification of past disadvantages due to apartheid, there are also negative implications for the economy due to the rapid growth in South Africa. One major concern with urbanisation is the rapid influx of households migrating to urban areas, which adds pressure to an already underperforming economy. Turok & Borel-Saladin (2014) identify that this increased capacity adds pressure to the economy and that these economies are forced to find ways to fund infrastructure development to avoid bottlenecks, traffic congestion, housing shortages, and polluted water courses. In South Africa, urban metropolitan areas have failed to keep up with formal housing development due to the rising rural-to-urban migration, leading to about 10% more households living in shacks than there were 10 years before 2014 (Turok & Borel-Saladin, 2014). The rate at which households and families live in slums due to urbanisation in South Africa is alarming. Slums are defined as urban areas with high populations and substandard housing with poor living conditions (Bodo, 2019). Households face numerous physical risks, including increased susceptibility to diseases, overcrowding, fire outbreaks, flooding, and other social and environmental hazards (Seeliger & Turok, 2014; Turok & Borel-Saladin, 2014). Research conducted by Moghayedi et al. (2023) reveals that the majority of South African townships are characterised by poor, inadequate, and substandard housing that lacks the security of tenure and fails to comply with building and planning regulations. These slum-like developments contribute to critical issues such as man-made disasters, crime, and suboptimal design due to the absence of standardisation. Consequently, the functionality, resilience, and health of residents are negatively impacted (Moghayedi, et al., 2023). The proliferation of slum areas is a consequence of rapid urbanisation. The combination of population growth in urban areas and the severe housing backlog, particularly in the affordable housing sector, results in an overwhelming demand that the industry struggles to meet. Consequently, households are forced to live in substandard housing while they await better provisions. Addressing this issue requires collaborative efforts from the private and public sectors to implement effective strategies and remedies that can meet the escalating demand for affordable housing amidst urbanisation.

Poverty, poor sanitisation, and disease spread:
The process of urbanisation can have detrimental effects on the food security of individuals who migrate from rural areas to urban centres. In rural settings, many individuals possess agricultural skills and rely on their crops for sustenance. However, upon relocating to urban areas, they often find themselves compelled to purchase food rather than cultivate it themselves. When the cost of purchasing food becomes unaffordable, these individuals may resort to scavenging for discarded or expired food as a means of survival (Bodo, 2019). Scholars have recognised that lower-income households in urban areas face heightened risks of disease transmission due to prevailing cultural, political, and economic factors (Ali, et al., 2023). Consequently, the longer these households are deprived of adequate housing, the greater the challenges they face in terms of health, well-being, and overall quality of life (Del Rio & Sovacool, 2023).

Waste and pollution:
Due to the increased demands for resources that come with the increase in population, there can be a negative impact on the land, water, air, and wildlife. A large population constantly growing in one area will not have a positive impact on the environment due to (Bodo, 2019):

- Blockages in drainage systems due to insufficient sanitation and sewerage systems.
- Toxic wastes from industries are being deposited into rivers, resulting in contaminated drinking water.
- Higher CO2 emissions from the increased number of cars.

Unemployment and Crime:
Slum-like developments present significant challenges, including widespread poverty, high unemployment rates, limited access to education, and unstable sources of income. Consequently, when households are compelled to migrate to urban areas and are only able to afford to live in such slum environments, they become vulnerable to various psychosocial issues, including increased crime rates, violence, and substance abuse (Moghayedi, et al., 2023). Many rural citizens embark on the journey of urban migration with hopes of a better future, seeking employment opportunities and an improved standard of living. However, the harsh reality is that a significant number of them find themselves without job prospects and end up facing homelessness. In such desperate circumstances, some individuals may resort to engaging in criminal activities as a means of survival and to sustain themselves financially (Bodo, 2019).

Reduced labour and resource underutilisation:
Urbanisation in South Africa has had both positive and negative impacts on the country's economy and society. While it has contributed to economic growth, social development, and the rectification of past injustices, it has also put pressure on the economy and led to inadequate housing, poverty, poor sanitation, and environmental degradation. One major issue is the influx of households migrating to urban areas, which has increased the demand for housing and led to the growth of slums. These areas, which are defined as urban areas with sub-standard housing and poor living conditions, are often overcrowded and expose residents to diseases, fire outbreaks, flooding, and other hazards (Seeliger & Turok, 2014; Turok & Borel-Saladin, 2014). The lack of affordable housing in South Africa has also contributed to the growth of slums, as many households are forced to live in sub-standard housing while they wait for better housing options. In addition, urbanisation has led to the depletion of natural resources and negative impacts on land, water, air, and wildlife (Bodo, 2019). This includes blockages in drainage systems, contaminated drinking water, higher CO2 emissions, and negative impacts

on local ecosystems. Unemployment and urban crime have also been linked to urbanisation in South Africa, as many rural residents migrate in search of work but end up struggling to find employment and resorting to criminal activity to make a living (Bodo, 2019). Finally, the migration of skilled workers from rural to urban areas has harmed the development and growth of these areas, as they are left with fewer skilled workers to drive economic growth and development (Mlambo, 2018).

2.4 South African Affordable Housing Crisis

With rising urbanisation, South Africa is facing a challenge in providing suitable, affordable housing to households. The housing sector has struggled to meet the increasing demand for affordable housing, resulting in a growing backlog. According to Figure 2.2, the delivery of affordable housing by the government has decreased significantly, from approximately 160,000 units completed in 2009/10 to just under 100,000 units completed in 2018/19 (Mahachi, 2021).

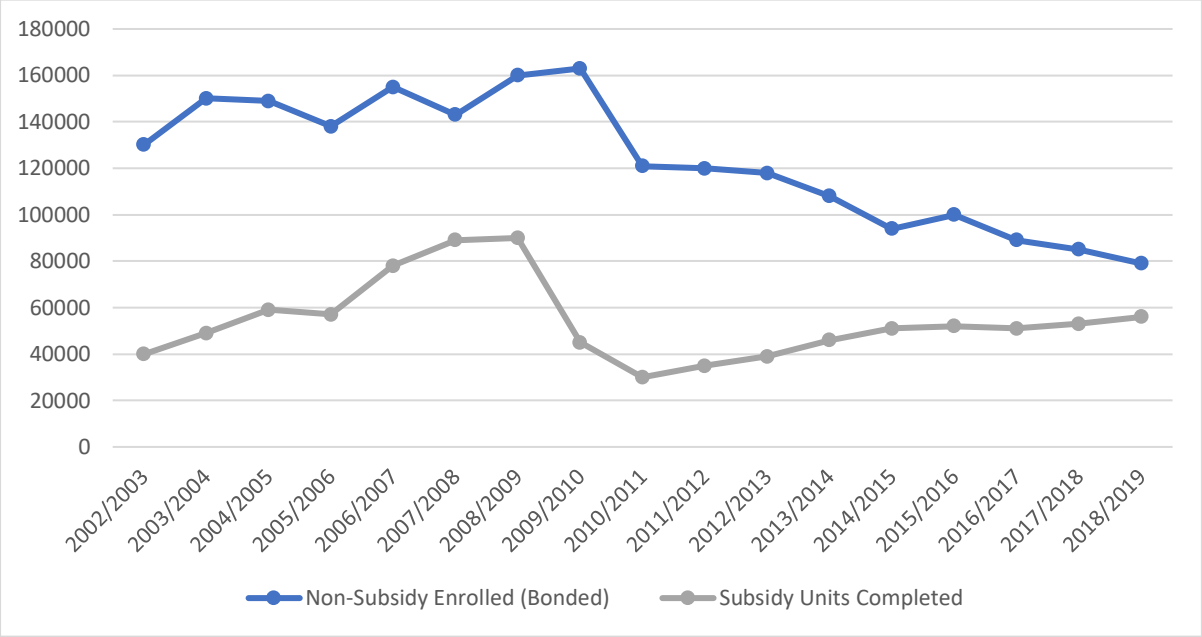


Figure 2.2 Delivery of South African housing (Mahachi, 2021).

Chakwizira (2019) notes that, although there has been some progress in addressing the issue of affordable housing in South Africa since 1996, it has not been sufficient to eradicate all informal housing, which is often a result of rapid urbanisation. Table 2.1 shows the distribution patterns of households from 1996 to 2016, highlighting the increase in informal housing over the years.

Table 2.1 Household distribution by type of main dwelling (census 1996 – community survey 2016) (Statistics South Africa, 2016).

Main Dwelling	Census 1996		Census 2001		Census 2011		Community Survey 2016	
	Number	(%)	Number	(%)	Number	(%)	Number	(%)
Formal Dwelling	5,834,819	65.1	7,680,421	68.5	11,219,247	77.6	13,404,199	79.2
Traditional dwelling	1,644,388	18.3	1,664,787	14.8	1,139,916	7.9	1,180,745	7.0

Informal Dwelling	1,453,015	16.2	1,836,231	16.4	1,962,732	13.6	2,193,968	13.0
Other	35,290	0.4	46,628	0.4	128,266	0.9	142,271	0.8
Total	8,967,512	100	11,218,067	100	14,450,161	100	16,921,183	100

Over the years, as the population has risen, so have the various forms of housing. The number of formal dwellings more than doubled from 1996 to 2016, while informal dwellings doubled in number by 2016. A significant contribution to the uneven spread of land is the negative spatial planning that was conducted during apartheid. This spatial planning has been a negative factor in the effort to eradicate informal housing due to urbanisation. However, Chakwizira (2019) highlights the change in planning instituted by former South African president Jacob Zuma (2009) towards the end of his term. The declaration by Zuma resulted in a shift in the Department of Housing's priorities, moving beyond the sole provision of affordable housing. The new focus is centred around the planning, provision, and management of human settlements that are spatially integrated, inclusive, and resilient. These settlements aim to align with norms and standards associated with spatial settlement efficiency, justice, economy, resilience, and good governance (Chakwizira, 2019).

This shift in focus changes the direction of the affordable housing provision in the country, not just focusing on providing housing to eradicate the backlog, but also bringing justice and equity. The shift in focus of the department is grounded in the conviction that equitable spatial planning holds the potential to revolutionise environments, fostering the development of inclusive spaces, vibrant communities, and diverse cultural experiences. This transformation aims to provide people with conducive settings to thrive, encompassing opportunities for work, living, and recreation in newly established urban areas. Despite government involvement and participation since South Africa's independence, which has resulted in positive efforts, in 1996 the Constitution of South Africa established the right of all South Africans to appropriate and adequate housing. Since 1994, the government has intentionally enforced laws to give full effect to this right (Mbandlwa, 2021). The public sector provided 2.3 million houses at that time to 11 million residents. Nevertheless, even though 26 years have passed since attaining independence, there still exist 2.1 million households without adequate housing as of 2020. Despite the controversy surrounding the matter, the Minister of Human Settlements has expressed the viewpoint that the government is not aiming to establish a community reliant on handouts, where individuals demand free homes from the state. The provision of housing serves as a safety net for the most vulnerable individuals among the impoverished population, but it cannot be sustained indefinitely. This acknowledgement underscores the government's recognition that it is not currently feasible to meet the demand for affordable housing on a large scale at a sustainable pace within the country. It is highly unlikely that the South African settlement strategy will completely meet the United Nations Millennium Development Goals for slum-free cities at this rate (Mbandlwa, 2021). As a result, a viable alternative is to create mandates or incentives for the private sector to play a role in affordable housing delivery.

2.4.1 Affordable Housing Defined

When considering the demographic of households that account for a large percentage of rural-to-urban migration, it is found that a large majority fall under the affordable housing bracket. However, the term affordable is highly subjective and can vary depending on an individual's background, upbringing, location, or financial position. Clearly defining affordable housing can be difficult due to these variables (Moghayedi, et al., 2021). Carswell (2021) notes that there is currently no consensus for determining the term “affordable” directly, but it can be defined using the housing expenditure-to-income ratio. This analysis covers the rental cost of the housing unit and the total costs of utilities (gas, oil, electricity, water, etc.). Yeganeh, et al.

(2021) define the term “affordable” as a household's rent-to-income ratio or house-to-price-to-income ratio. Anacker (2019) argues that increased housing costs will have negative effects on a household's budget. High expenditures can decrease the standard of living and opportunities available to a household, eventually leading to slum-like living conditions. Using the expenditure-to-income ratio method, affordable housing can be defined as housing that does not exceed more than 30% of the occupant's income (Carswell, 2021; Jones & Stead, 2020). An example that illustrates the subjectivity of the concept of affordable housing is the scenario in which an occupant with a monthly income of R15 000 after tax spends R7 500 each month, including all housing-related costs such as utilities, which equates to 50% of their income. This surpasses the common definition of affordable housing, which stipulates that housing expenses should not exceed 30% of the occupant's income. In this case, a feasible rent option would be R4 500, which adheres to the 30% threshold for the prospective occupant's income. Nonetheless, while this definition is useful, it does not discount the subjective nature of housing affordability. For instance, if an occupant's net income is R50,000 or more each month, their housing arrangement may not be considered affordable if it exceeds 30% of their monthly income. For instance, with an expenditure of 30% of their monthly income, a resident with a monthly living expense of R15 000 could afford to rent a 3-bedroom apartment in Bryanston, Johannesburg. To create a more specific definition, the target market should be narrowed down to households that qualify for the Finance Linked Individual Subsidy Programme (FLISP) programme. Households that qualify for this program will often earn between R3501 and R22 000 per month (SA Home Loans, 2022). Taking the average income from this bracket, the ideal occupant would have an income of R12 750.5 per month and a housing expenditure of R3 825.15 per month. To conclude the proposed definition, using the expenditure-to-income ratio, affordable housing can be categorised as housing that does not exceed more than 30% of the occupants' income, given that the household income is between R3501 and R22 000 per month.

2.4.2 Affordable Housing Backlog and Affiliated Consequences

What remains present within South Africa is the ever-growing backlog in affordable housing. The significant number of families in need of affordable housing stands in contrast to the principles outlined in human rights law. According to the United Nations Publications (2012), human rights law stipulates that every individual has the right to a suitable standard of living for themselves and their families, which encompasses access to adequate food, clothing, and housing, along with the ongoing enhancement of living conditions. However, since 2013 the 2 million affordable housing deficit has not decreased. In fact, the affordable housing backlog has grown to 3.7 million around 2020, and this figure is expected to grow by 178,000 annually. Regardless of the right humans have to adequate housing, a law recognised by hundreds of countries, the world, including South Africa, is facing a global housing crisis (Marutlulle, 2021). Across the globe, builders, planners, and policymakers are seeking ways to address the significant housing backlog. Research from the United Nations (UN) has found that within the next 25 years, 3 billion people will need access to housing and basic infrastructure services, which equates to 35.1 million housing units per year, or 96,150 per day, or 4,000 per hour to meet the demand (Marutlulle, 2021). Additionally, millions of people are frequently moving or being born into cities, and as a result, the UN estimates that by 2050, 3 billion people will be living in slums due to the trajectory of the global housing situation (Marutlulle, 2021). The University of Dublin - Trinity College has articulated the all-encompassing nature of the problem, stating that great challenges arise when there is a constant lack of adequate housing. This not only challenges social and economic development but also places great pressure on the environment, health and education systems and threatens social cohesion - a particular concern in South Africa given the country's history (Marutlulle, 2021).

2.4.3 Unveiling the Factors Influencing the Affordability of Affordable Housing Initiatives

Households around the world are experiencing the rising costs of financing a home. These households report that housing prices are expensive and unaffordable, and they feel heavily burdened by the weight of their housing financing responsibilities (Salvi del Pero, et al., 2016). The problem for most households is that the increase in housing costs is not accompanied by a corresponding increase in income. In 2007, there was a global recession, which caused the cost of housing to decrease substantially, making it a buyer's market. However, in the third quarter of 2012, housing prices began to rise while incomes remained stagnant, indicating the start of the housing unaffordability crisis (Salvi del Pero, et al., 2016). As a result, the affordability of housing is likely to decline for lower-income households due to the uneven pace at which income groups have been recovering from the recession. Anacker (2019) agrees and notes that housing affordability has declined over time, leaving homeowners unable to pay for necessities such as food, utilities, transportation to work, healthcare, and childcare, as well as reducing their ability to save and invest in education or start a small business. Researchers identify that the affordability of housing is a complex issue that goes beyond the limits of average housing prices and income level ratios (Perera & Lee, 2021). The complexity of addressing the cost of housing is of high magnitude. Nevertheless, the affordability of housing boils down to a household's ability to purchase or rent housing within their income level; if the cost exceeds 30% of the occupant's income, it is deemed unaffordable. While there are traditional methods to understand the cost of housing (e.g., rent, electricity, and water bills), factors such as transportation costs, neighbourhood quality, energy efficiency, housing quality and density also impact the affordability of a home (Mulliner, et al., 2016). Ultimately, there are a few main reasons for the rising costs of affordable housing post the global crisis. First, land is a finite resource, and as time goes on, there is less land available for development. This results in higher costs to equate the higher value of the land, especially in highly dense urban areas (Arashpour, et al., 2014). In many cities around the world, developers are building higher-rise buildings instead of building outwards in residential living spaces due to a lack of land (Peterson, 2018), for example, in the city of Cape Town in the Western Cape. Second, the rise in housing prices is attributed to the rising costs of construction materials over time (Jakabovics, et al., 2014), as well as tighter planning regulations and standards that prohibit faster development. Geithner (2014) argues that higher lending standards to construction companies also caused a spike in housing costs. Third, rents and housing prices have gradually increased as home developers have shifted focus toward developing housing for households that fall under the upper-income bracket (Sherman, 2017). This focus is profitable, but it does raise the market price for housing around it. Anacker (2019) identifies that due to the gentrification of older cities/areas, landlords are forced to tear down old units to conform to code issues, but these re-established units are replaced by higher-income housing. Fourth, in many countries, there is reduced funding for affordable housing (Lennartz, 2017). This is a governmental issue that often inhibits the development of such housing types. Solving the issue of housing unaffordability is a concern that is constantly on the radar of numerous countries (Anacker, 2019). However, fully addressing it comes with its challenges. Anacker (2019) highlights that it is difficult to decrease household expenses and increase household incomes, as both expenses and incomes only grow gradually over time. Without immediate affirmative action from policymakers, households can be left in difficult situations, often resulting in suicides (Fowler, et al., 2015), immediate evictions (Desmond, 2016), crime (Ellen & Lacoe, 2015), and health crises (Currie & Tekin, 2015). To address the unaffordability of affordable housing, Anacker (2019) suggests the following solutions:

- Constructing new affordable housing units on vacant urban land zoned for multifamily development.

- Converting already existing single-family homes into multiple units or subdividing them.
- Constructing units on underutilised urban land zoned for multifamily development.
- Encouraging local government to approve planned affordable housing through incentives.
- Streamlining the land-use approval process.
- Allocating funding for affordable housing as a priority for local government.
- Attracting new investors in affordable housing.
- Boosting construction productivity.
- Utilising modular construction techniques.
- Expediting construction permitting processes.
- Minimising the costs of operating affordable housing.

2.4.4 Quality of Affordable Housing

Although there is a rising backlog in affordable housing, the delivery of these housing types must increase in conjunction with the quality of the affordable house. Access to good quality affordable housing is an important factor that benefits various social policy objectives, including poverty reduction, equality of opportunity, and social inclusion (Salvi del Pero, et al., 2016). Without access to good-quality affordable housing, people will not be able to meet their basic needs and participate adequately in society. A housing space should not only provide a suitable place to sleep and rest, but it must also include safety, privacy, personal space, and the ability to successfully raise a family. However, many countries across the globe are still faced with inadequate housing conditions. The poor quality of affordable housing encompasses three main aspects: inadequate living spaces, substandard sanitary conditions, and a lack of quality in the surrounding neighbourhood (Salvi del Pero, et al., 2016). Further studies identify that a major reason for the poor quality of affordable housing is linked to the issue of poor quality and unsustainable material use in housing projects (Jeaune, et al., 2021). The study further alludes to the fact that with less usage of sustainable building materials, there will be a negative impact on the economy, communities and environment, particularly for low-income households. Further studies argue that in the foreseeable future, to improve the quality of affordable housing, building materials should be sustainable in order to address technical, environmental, social and economic issues that normally arise due to the use of conventional building materials (Omer & Noguchi, 2020; Jeaune, et al., 2021).

2.4.4.1 Defects in Affordable Housing:

The quality of housing development is significantly influenced by the selection of construction methods and materials. Previous research emphasises the negative consequences of using inadequate methods and materials, leading to defects and poor quality in housing projects (Moghayedi & Windapo, 2019). Substandard construction methods, low-quality building materials, and insufficient soil analysis are often cited as contributors to the prevalence of defects in affordable housing (Monghasemi, et al., 2015; Ferrada & Serpell, 2014). Abdul-Rahman et al. (2014) provides further evidence of the defects that can arise from poor construction methods and materials, as outlined in Table 2.2. These defects encompass various aspects of the building, including the foundation, walls, floors, roofs, and external works. The consequences of such defects are particularly detrimental to lower-income households, who are disproportionately affected by housing issues due to their limited budgets (Abdul-Rahman, et al., 2014). However, it is essential to recognise that financial constraints should not justify the provision of substandard housing for lower-income groups. Rather, the careful consideration of construction methods and materials, along with the utilisation of multicriteria decision analysis techniques, can greatly improve the quality, efficiency, and sustainability of

housing development projects (Moghayedi & Windapo, 2019). By selecting appropriate methods and materials, construction professionals can mitigate the risks associated with defects and poor quality, ensuring optimal outcomes for all stakeholders involved.

Table 2.2 The summary of causes of defects (Abdul-Rahman, et al., 2014)

No.	Causes of Housing Defects	Description:
1	Design	Defects resulting from errors or shortcomings in the initial design of the building.
2	Aging	Defects that occur over time as a result of natural wear and tear or degradation of materials.
3	Construction	Defects arising from errors or deficiencies in the construction process, such as poor workmanship or improper installation.
4	Vandalism	Damage caused intentionally by acts of vandalism or malicious activities.
5	Changing Standards	Defects caused by changes in building codes, regulations, or industry standards that render certain aspects of the construction non-compliant.
6	Client	Defects resulting from the client's requirements, specifications, or decisions that may impact the quality of the project.
7	User Involvement	Defects that arise due to insufficient input or feedback from the end users or occupants of the building during the design or construction process.
8	Time Pressure	Defects that occur when projects are rushed or completed under tight deadlines, leading to compromised quality.
9	Cost Pressure	Defects arising from budget constraints or attempts to cut costs, which may result in the use of inferior materials or inadequate construction methods.
10	Workers Problem	Defects caused by issues with the workforce, such as lack of skills, poor training, or negligence.
11	External Influence	Defects that result from external factors beyond the control of the construction team, such as natural disasters or environmental conditions.
12	Tenant’s Lack of Care	Defects caused by improper maintenance or neglect by the building occupants or tenants.
13	Material Selection	Defects arising from the use of inappropriate or low-quality materials during construction.
14	Poor Site Investigation	Defects caused by inadequate assessment or understanding of site conditions before construction, leading to unforeseen challenges or issues.
15	Management	Defects resulting from poor project management, including coordination, communication, and oversight.
16	Lack of Quality	Defects that occur when the overall quality of the construction project falls below acceptable standards or expectations.

The causes of poor-quality affordable housing can be grouped into four main categories: design and construction, collaboration and communication, policies and procedures, and tenants' involvement. Each of these plays a significant role in the process of delivering affordable

housing, and if any step in the supply chain is not carried out effectively, it can result in a poorly delivered home with various defects. These defects can create additional financial burdens for low- and low-middle-income households, who may struggle to afford the cost of repairs. As a result, these households may be forced to live in poorly constructed homes with various defects, unable to address the issues due to financial constraints.

2.5 Affordable Housing Supply Chain

2.5.1 Stakeholders Involved in the Affordable Housing Supply Chain

Effective teamwork and collaboration are crucial elements in the successful delivery of high-quality affordable housing. Throughout the entire process, from design and construction to maintenance and operation, it is essential for all parties involved to communicate effectively and work together harmoniously. The construction industry, in particular, relies heavily on the cooperation and coordination of numerous stakeholders, making effective teamwork even more critical. As Shahparvari et al. (2019) have emphasised, the larger the project team, the greater the challenges in achieving seamless coordination and collaboration. With multiple stakeholders involved, errors and delays in the design process can become more prevalent. It is crucial to address these challenges and find innovative solutions, especially considering the decline in government delivery of affordable housing since 2009 and the increasing backlog in the affordable housing demand (Mahachi, 2021).

2.5.2 Operational Challenges in Supply Chain

Regardless of whether a company is private or public, there are always various stakeholders that play key roles in delivering affordable housing. The most important characteristic of any company is its ability to effectively collaborate to achieve the desired result. However, due to the slow nature of the construction industry, there are often inefficiencies that hinder the effective delivery of affordable housing. These inefficiencies may include prolonged construction periods, miscommunication and mismanagement between design teams, lack of coordination and collaboration, a lack of innovation, and rework caused by errors in collaboration and miscalculations (Shahparvari, et al., 2019).

2.5.2.1 Lack of communication:

Effective communication and collaboration between stakeholders at the beginning of a project increase the understanding of roles, responsibilities, and tasks. According to Shahparvari et al. (2019), this type of communication can reduce major design and production errors that negatively impact construction time, project costs, and the learning process during the project. Research from Shahparvari et al. (2019) also found that ineffective communication from stakeholders can result in unintended changes in designs and rework, which require new resources and materials, the identification of new suppliers, and ultimately lead to project overruns.

2.5.2.2 Lack of coordination and collaboration:

Findings from Shahparvari et al. (2019) identify coordination and collaboration as key elements in eliminating errors in design and rework. Rework has the potential to negatively impact a construction project by increasing material costs and prolonging the project's lifecycle. The longer a project takes to complete, the higher the financial burden it becomes (Buchanan & Gardner, 2019). Further research suggests that subcontractors in projects often view contractors as their clients rather than stakeholders in the supply chain. As a result, in order to maximise profits, subcontractors may try to minimise costs by cutting corners, which can lead to defects in design that are only detected later in the project's lifecycle (Shahparvari, et al., 2019). Such

defects can be avoided when effective collaboration exists between all stakeholders, including subcontractors and contractors.

2.5.2.3 Rework:

The largest contributor to rework in construction projects is often attributed to poor communication and coordination between stakeholders. This can lead to errors in design, mismanagement, and a lack of innovation, all of which can result in the need for rework. According to Shahparvari et al. (2019), subcontractors may view contractors as their clients rather than stakeholders in the supply chain, leading to a focus on minimising costs and potentially cutting corners, which can result in defects in design that are only discovered later in the project. To avoid rework, it is important to identify and address the root causes that may contribute to it, rather than simply fixing the problems that result from it (Shahparvari, et al., 2019). Figure 2.3, adapted from Arashpour et al. (2014) and Fong & Shahparvari (2018), illustrates the contributors and root causes of rework in construction projects:

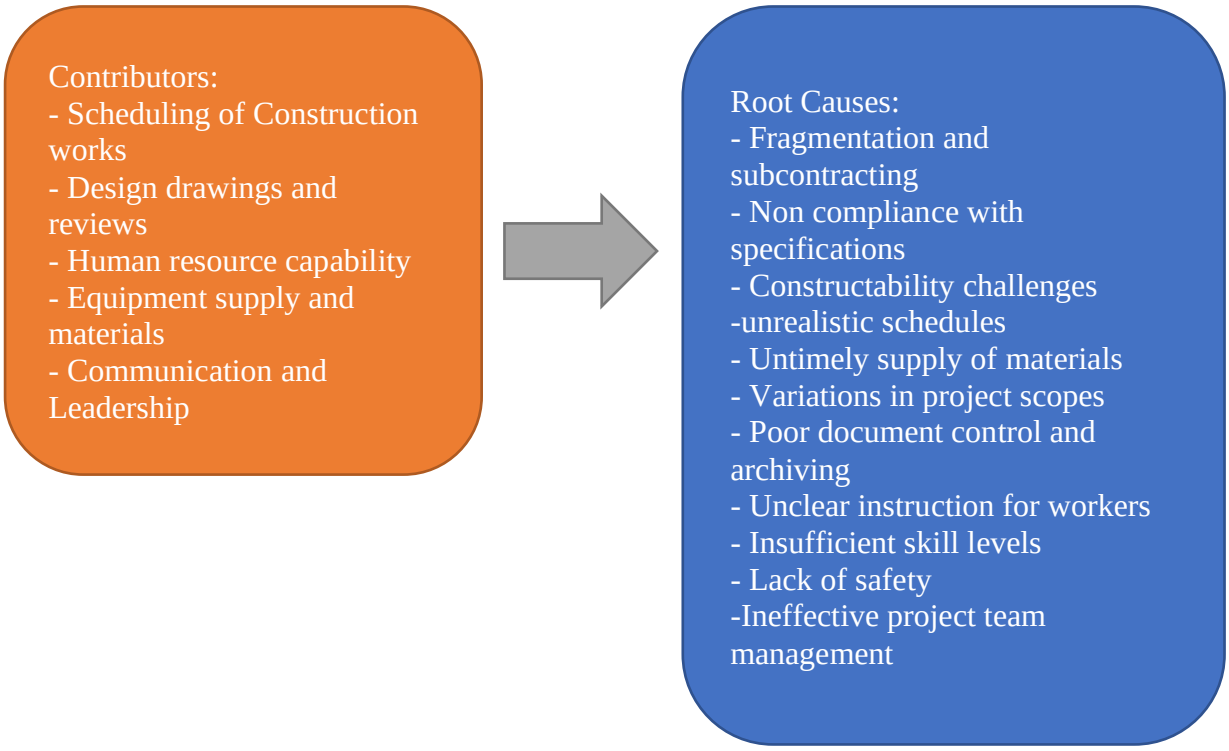


Figure 2.3 Contributors and root causes of rework in construction projects (Arashpour, et al., 2014; Fong & Shahparvari, 2018)

2.5.3 Consequences of Ineffective Supply Chains

As argued, when it comes to the delivery of an affordable house, there are several factors, steps and parties involved to produce the final output. Therefore, companies need to consider having an effective supply chain. The supply chain is a system of all the parties and functions, both within and outside an organisation, that work together to meet a customer's needs. This includes manufacturers, suppliers, transporters, warehouses, retailers, and customers, as well as any functions within each organisation that contribute to this process directly or indirectly. Similar definitions from Fernando (2022) address that supply chain management focuses essentially on the production flow of goods and services which addresses the way raw materials immerge into the final product. The consequences of having an ineffective supply chain in the construction industry can be far-reaching and can impact a company's ability to produce and

deliver affordable houses. These consequences can include delays in production and delivery, increased costs, and poor quality control. A significant consequence of an ineffective supply chain is the delay in production and delivery. Construction sites constantly need the delivery of materials and resources on-site, when these resources aren't delivered on time, it can disrupt the construction process and lead to delays in the completion of affordable housing projects. As with most things, these delays can result in additional costs for the company, resulting in paying for overtime of staff or incurring storage fees for materials that are not used in a timely manner. Such delays can also lead to severe customer dissatisfaction, as individuals may have to wait long for their affordable houses to be completed, as seen frequently in South Africa. Such claims are best justified by specified professionals dealing with supply chain efficiency, their claim is that an effective supply chain model helps streamline delivering the product in an efficient manner, which ultimately reduces the costs of production and will, in turn, result in customers receiving products at lower costs (Robert H. Smith School of Business, 2023).
In addition to the delays in delivery, an ineffective supply chain can also result in heightened costs for construction companies involved in affordable housing delivery. If the supply chain is not functioning efficiently, it can lead to higher costs for materials and resources, which can ultimately impact the affordability of the houses being produced (Robert H. Smith School of Business, 2023). After examining the seriousness of having a poorly planned supply chain, one can deduce the various challenges that may arise within the context of construction projects. Hence, ineffective supply chain management systems can result in waste or loss of materials which can lead to additional costs for the company. Another consequence of an ineffective supply chain is poor quality control. When materials and resources are not properly managed and tracked, it can lead to issues with the quality of the affordable houses being produced. As with prolonged delivery, poor quality control can result in customer dissatisfaction, and less social acceptance and may even lead to legal issues for the company. Ultimately, an ineffective supply chain model can cause serious consequences for construction companies attempting to produce and deliver affordable houses. These can result in prolonged delays in delivery which doesn't reflect well on the backlog in affordable housing South Africa is faced with, poor-quality control which can result in negative reputation communities may have with construction companies and potential strategies they offer and can ultimately compromise the affordability of the houses being produced. As a result, innovative strategies should be considered to overcome the serious negative effects of a poor supply chain model in construction companies. Innovative strategies could include the usage of technologies which could have a positive effect on the supply chain, and directly have positive effects on the current affordable housing backlog crisis.

2.6 Technological Solutions: Harnessing Innovative Technologies for Affordable Housing Delivery

The housing industry has been slow to embrace technological advancements, often due to resistance to change among industry professionals, particularly in South Africa where conventional construction methods are predominantly used (Mishra, 2017). However, studies indicate that the integration of innovative technologies holds great promise in overcoming barriers to affordable housing provision (Bennett, et al., 2019; Moghayedi, et al., 2021). Adopting innovative construction practices is crucial for delivering affordable housing that is socially suitable, and economically viable (De Villiers, et al., 2013). Implementing smart technologies in affordable housing has shown significant potential for improving energy and water consumption, reducing costs, and enhancing management decision-making efficiency during the design and development stages (Windapo & Moghayedi, 2020). By leveraging these technologies, the housing industry can effectively address critical challenges and optimise the delivery process. Innovative technologies have the capability to minimise design errors and

rework, promote collaboration across the construction supply chain, and reduce production costs (Shahparvari, et al., 2019). However, resistance to change and limited resources pose obstacles to widespread technology adoption in the industry. To overcome these hurdles, the housing industry must embrace digital solutions and collaborative platforms, streamlining processes, enhancing data sharing, and fostering collaboration among stakeholders. By investing in innovative technologies, the housing industry can drive greater efficiency and cost-effectiveness in affordable housing delivery, paving the way for a more sustainable and impactful future.

2.7 Utilising Innovative Technologies to Address Affordable Housing

According to Shahparvari et al. (2019), digitalisation holds great promise in enhancing manufacturing workflows and can be extensively integrated into the housing supply chain to eliminate rework. However, Wortmann et al. (2016) argue that government enforcement of such technologies at a legislative level could be a positive catalyst for their effective adoption, compelling the industry to embrace digitalisation, as Shahparvari et al. (2019) suggest. Innovation in technology emerges as a vital tool for improving the overall affordable housing sector. However, Mahachi (2021) contends that the lack of enthusiasm towards the adoption of innovative technology stems from various factors, including inadequate collaboration between technology suppliers and contractors, insufficient knowledge transfer between projects, apprehension among built environment professionals, and misconceptions regarding associated costs. Understanding how these technologies related to the Fourth Industrial Revolution, coupled with housing delivery strategies, can enhance the provision of affordable housing in South Africa is of utmost importance (Osunsanmi, et al., 2018). Scholarly articles frequently mention these innovative technologies, encompassing Building Information Modelling (BIM), the Internet of Things (IoT), 3D Printing, Virtual Reality, cloud computing, and Unmanned Aerial Vehicles (UAV), among others. However, the construction industry in South Africa often displays a lack of enthusiasm towards adopting innovative technology, resulting in decreased productivity and a dearth of dynamism and creativity (Mahachi, 2021).

2.7.1 Innovative Technologies within Developing Nations

The advancement of innovative technologies is occurring at an accelerated pace, particularly within the realm of fourth industrial revolution technologies, and it has yielded significant benefits for millions of people worldwide, primarily in developed nations. However, ‘Utoikamanu (2018) highlights a significant concern: these technological advancements primarily favour developed nations, leaving least developed nations behind or excluded from reaping these benefits. Common assumptions often suggest that developing nations lack the determination or will to catch up with their developed counterparts. However, ‘Utoikamanu (2018) argues that the exclusion of developing nations from technological progress stems from a multitude of challenges, including the persistent struggles of eradicating poverty, the inability to establish sustainable development practices, and inadequate participation in the increasingly competitive global market. Structural limitations pose one of the primary hurdles faced by developing nations. Their inability to compete on a global scale creates significant market gaps compared to developed nations, resulting in limited resources in crucial areas such as science, technology, and innovation ('Utoikamanu, 2018). Consequently, underdeveloped nations encounter numerous obstacles in their developmental pursuits due to these overarching limitations. Furthermore, Oyelaran-Oyeyinka & Lal (2006) argues that implementing innovative technologies, such as Information and Communication Technologies (ICTs), becomes increasingly challenging for businesses in developing nations. While ‘Utoikamanu (2018) notes the absence of structural limitations, these nations struggle with a lack of education, skills, and knowledge transfer, making it increasingly difficult to learn and embrace

these newer technologies without formal education. Thus, there is a pressing need to address the deficiencies in educational systems. When it comes to the adoption of innovative technologies in developing nations, several factors contribute to the challenges at hand. Poor business models that fail to promote their adoption, political instability, limited access to education and knowledge transfer, a dearth of world-class research universities, and a shortage of adequately trained human resources are all significant hurdles that impede progress (Ali, et al., 2009).

2.7.2 Enhancing Affordable Housing Delivery with Innovative Technology

At its core, innovation embodies the successful materialisation of original ideas, as noted by Moghayedi et al. (2021). When applied to the domain of affordable housing, it encompasses novel approaches to its development. However, innovation transcends mere technological advancements and encompasses social and behavioural changes as well, as emphasised by Taylor (2017). According to Moghayedi et al. (2021), innovative practices within the housing context entail the practical implementation of previously understood housing concepts, resulting in the introduction of new, enhanced, and cost-effective housing solutions. Harnessing innovation has the potential to expedite the delivery of affordable housing, which is significantly hindered by the mounting backlog experienced in South Africa. Mahachi (2021) sheds light on key challenges such as escalating construction costs, limited access to raw materials, inexperienced contractors, and a lack of awareness and recognition of advancements in building technologies. These challenges perpetuate the backlog, impeding the timely provision of adequate housing options. Purposefully embracing innovation within the affordable housing sector can effectively address these inefficiencies in housing delivery. By actively embracing innovative approaches, the affordable housing sector can navigate the obstacles it presently encounters. By actively seeking fresh ideas and alternative methodologies, the sector can unlock new avenues for progress. This intentional gravitation towards innovation not only facilitates enhanced efficiency in housing delivery but also establishes a solid foundation for improved outcomes in the provision of affordable housing.

2.7.3 Advantages of Innovative Technologies in Affordable Housing

The use of innovative technologies often results in practical advantages that generally improve overall efficiency and decrease production costs in the long run. According to a panellist in a featured article based on a webinar proceeding hosted by the Bipartisan Policy Centre, McCoy (director of the Virginia Centre for Housing Research at Virginia Tech) argues that newer technological practices in housing development will make the process faster and cheaper than ever before (PD&R EDGE, 2022). For instance, the use of technology such as robotics will immediately reduce labour costs as these technologies can take on repetitive tasks such as 3D printing and bricklaying, while other machines can perform complex tasks such as welding, painting, or repaving. This will decrease costs substantially - the study even suggests by 20% - and it will also improve the delivery rate significantly. However, these technologies will not only impact overall efficiency and reduce costs, but McCoy argues that by leveraging innovative technologies, such as robotics, automation, and advanced monitoring systems, tasks that pose a higher risk to human workers can be delegated to machines. This enables safer execution of hazardous activities, minimising the potential for accidents and injuries (Moghayedi, 2016). Additionally, the use of sensors and real-time data analysis can provide early warnings and alerts for potential safety hazards, allowing for prompt intervention and preventive measures. In addition, virtual reality and simulation technologies offer opportunities for training and practising evading such dangerous situations in a controlled environment, further reducing the exposure of workers to risky conditions on-site (Moghayedi, 2016).

Some innovative technologies even allow remote access, where various equipment can be operated using computers, and the use of UAVs can aid in monitoring the efficiency of these remotely working machines (PD&R EDGE, 2022). When it comes to the implementation of innovative technologies such as prefabrication and modular construction, most homes can be manufactured off-site, which is often argued to result in minimal design issues and less rework due to the accurate nature of manufacturing in controlled environments (Bertram, et al., 2019). Ultimately, each technology type will be of significant benefit to the affordable housing sector as the benefits range from minimised production costs, higher safety on site, remote working accessibility, surveillance and monitoring off-site, minimised design errors and rework on projects, and improved affordable housing efficiency.

2.7.4 Challenges and Barriers to The Adoption of Innovative Technologies within South African Affordable Housing Projects

Despite the inherent advantages of innovation in affordable housing projects, several challenges and barriers persist, impeding the complete adoption of innovative technologies. These obstacles arise from various factors, encompassing market irregularities, legal, financial, and cultural aspects.

One of the noticeable challenges is the irregular nature of the South African market for building materials. Windapo & Moghayedi (2017) identified the significant differences in the average prices of essential materials across different geographic locations. It was further examined that the prices of cement, steel, timber, clay bricks, and bitumen in KwaZulu-Natal, Gauteng, and Western Cape provinces vary immensely. As a result, these variations in building material prices across different geographic locations may impact the cost-effectiveness and feasibility of implementing innovative technologies in affordable housing projects. Windapo & Moghayedi (2017) further identified that location plays a significant role in building material price differentiation, indicating the need for standard development plans and the exploration of alternative and innovative construction technologies in areas with comparatively high price differentials. If this is not overcome, the increased prices for essential building materials in certain areas could increase the overall construction costs when adopting innovative technologies. This may pose a challenge for developers and builders who are already facing cost constraints in delivering affordable housing.

Another significant challenge pertains to the legal framework surrounding the adoption of innovative technologies. Often, the regulatory environment lacks clear guidelines and standards specifically tailored to these emerging technologies, presenting difficulties for developers and stakeholders in navigating the legal landscape (Wortmann, et al., 2016). The sluggish pace of updating and adapting regulations to accommodate new technologies can result in uncertainties and delays during the approval process. Financial constraints pose another significant barrier. The upfront costs associated with innovative technologies can be prohibitively high, including expenses related to acquiring and installing new systems and equipment. Such financial burdens become particularly challenging for developers operating within limited budgets and resource constraints. The lack of accessible financing options tailored to support the adoption of innovative technologies exacerbates the financial barrier.

Cultural and societal factors also impede the adoption of innovative technologies in affordable housing projects. Resistance to change and a preference for traditional construction methods within the industry hinder the acceptance and integration of new technologies (Mahachi, 2021; Shahparvari, et al., 2019). Limited awareness and understanding of the potential long-term benefits and value of innovative technologies contribute to scepticism and reluctance in adopting these solutions. Additionally, the dearth of skilled individuals and technical expertise presents a prevailing issue in South Africa. Effectively harnessing these technologies necessitates a proficient workforce capable of operating, maintaining, and optimising their

functionalities. However, a shortage of trained professionals and limited access to specialised training programs contribute to the existing skills gap within the industry. Addressing these challenges and barriers requires a comprehensive, multi-faceted approach. It entails establishing clear guidelines and regulations within the legal framework, specifically tailored to innovative technologies in affordable housing projects. Providing financial incentives and accessible financing options targeted at supporting the adoption of these technologies can alleviate the financial burden for developers. Educating and raising awareness among industry stakeholders through campaigns can foster a culture of innovation and enhance understanding regarding the benefits and value of embracing new technologies. Additionally, investing in training programs and capacity-building initiatives can equip the workforce with the necessary skills to effectively utilise and maintain innovative technologies. By addressing these challenges and barriers, the adoption of innovative technologies in South African affordable housing projects can be accelerated, leading to improved efficiency, sustainability, and affordability in housing delivery.

2.7.5 Impact Innovative Technologies Have on The Delivery Process of South African Affordable Housing

Although there is a multitude of innovative technologies that have come to fruition due to the rapid technological growth caused by events such as the fourth industrial revolution, each of these technologies has a multitude of benefits. Numerous sets of these innovations have a positive impact on the delivery rate of affordable housing or at least the development process of housing projects. For example, Bertram et al. (2019) advocate that modular construction technologies and their counterparts are used to improve productivity during the development of housing projects. These technologies are documented to improve construction delivery by 20-50%. However, modular construction technologies tend to have a direct impact on affordable housing delivery, while other technologies such as BIM, GIS, and other design software would have an indirect impact on the delivery rate of affordable housing. Research conducted by Redmond et al. (2012) highlights that BIM technology helps stakeholders make crucial decisions and mitigate errors in the early stages of development, thus minimising rework that could occur if those issues weren't addressed earlier. Due to the proactive nature of BIM and other innovative design software, design, implementation of designs, and construction will be done at an efficient rate, ensuring the project is delivered according to the given timeline. However, with more advanced technologies such as artificial intelligence and robotics, a natural by-product of implementing these technologies results in efficiency, accuracy, and reliability. Such technologies are designed to conduct repetitive tasks such as bricklaying, painting, or demolition. The rate at which these technologies can perform these tasks is substantially faster than human performance, thus construction sites can see heightened productivity and minimised time taken to turn over the project (Rao, 2022). Taking into consideration the different benefits and impacts innovative technologies can have on the development of affordable housing, various technologies such as modular construction, 3D printing, and artificial intelligence will have a direct impact on the overall delivery of affordable housing, while technologies such as BIM, GIS, smart sensors, virtual reality, and augmented reality tend to impact affordable housing delivery due to their positively attributing components.

2.7.6 Impact That Innovative Technologies Have on The Affordability of South African Affordable Housing

The term affordable already includes its own complications when being defined, so the affordability of an affordable housing project includes various components that not only relate to the costs of building the project but also to aspects such as distance to work and location. In

recent decades, housing affordability has significantly declined for most low-, very low-, and extremely low-income renters, making it nearly impossible to afford to pay for a house, leaving less income for expenses such as food, utilities, transportation to work/school, health and childcare, savings, and other investment opportunities (Anacker, 2019).
When considering the possibility of adopting innovative technologies to benefit the affordability of affordable housing, these factors must be addressed:

- (1) The technology should minimise the costs of housing production, and
- (2) The long-term end-user costs should be minimised when implementing these technologies in construction.

2.7.6.1 Minimalised Cost of Production:

When considering the cost of production of affordable housing projects, several factors come into play, including, the design process, the construction process, and the cost of materials.
When implementing technology with the goal of reducing the cost of production, the technologies can be used for these purposes individually or as a whole. For example, Project Portfolio Management is often used to ensure that the construction project as a whole minimises project risks (Barbosa & Rodrigues, 2020) and stays within budget by following a detailed process map that keeps the project team accountable and up-to-date with the project plan (Lynn, 2022). This technology is beneficial in both the design and construction process, as it helps to minimise risks and avoid rework, which can add to production costs (Martinsuo, et al., 2014). Technologies such as BIM are known for detecting design clashes, which can also help to avoid rework. According to a survey by Farnsworth et al. (2015), clash detection is one of the top 5 advantages of BIM as identified by industry professionals. In this survey, clash detection was ranked 5th under communication, scheduling, coordination, and visualisation. BIM's collaborative nature (Thurairajah & Goucher, 2013) allows various stakeholders to identify clashes at the architecture, engineering, or quantity surveyor level, which can help to avoid rework costs caused by design clashes. Similar principles can be applied to technologies such as Virtual Reality, which can create an immersive experience for the design team to virtually walk through their designs (Brooks, 2022), and Augmented Reality, which can easily detect errors and clashes in designs (Nassereddine, et al., 2022).

However, when considering the construction process, innovative technologies such as modular construction and 3D printing have a few common traits that can decrease the costs of production. These technologies:

- Reduce labour costs.
- Provide accuracy in construction, resulting in minimal rework on site.

When using modular construction, construction companies will often manufacture the components off-site in a controlled environment, assisted by robotics using artificial intelligence to conduct repetitive tasks (Rao, 2022). This accuracy will align with the accuracy of the housing designs, ultimately resulting in houses that are simply assembled on-site with reduced labour needs, thus reducing labour costs, and minimising rework. 3D printing works in a similar manner. It aids in the speedy delivery of construction projects, avoiding costs due to delays in housing projects (Buchanan & Gardner, 2019). The technology also uses robotics to print the project, which minimises errors in construction due to the accuracy of the robots. Labour costs are also reduced when using this technology.

It is clear that the usage of certain technologies can aim to reduce the cost of production, however as briefly mentioned, a crucial component to consider is the cost of materials when aiming to minimise the cost of production. However, considering the current irregularity in the market for building materials in South Africa due to the substantial differences in average

prices of essential building materials across various regions, this can significantly impact the feasibility and affordability of housing projects aimed at low-income individuals and families (Windapo & Moghayedi, 2017). Affordable housing initiatives face the challenge of limited financial resources, making it crucial to optimise costs without compromising the quality and safety of the structures. The variations in building material prices directly affect the overall construction costs and, consequently, the affordability of housing units. When prices are inflated in specific geographic areas, it becomes increasingly challenging to deliver cost-effective housing solutions that meet the needs of low-income households (Windapo & Moghayedi, 2017). It is crucial to acknowledge that the adoption of innovative technologies is not a standalone solution. The irregularities in building material prices highlight the complex interplay of various factors that influence the affordability of housing, including supply chain dynamics, competition within the market, and regional disparities. Addressing material costs requires a comprehensive approach that considers not only the adoption of innovative technologies but also policy interventions, strategic partnerships, and targeted support for the affordable housing sector.

2.7.6.2 Minimised End-User Costs:

One must always consider the end-user when determining the affordability of affordable housing when the house has been handed over. According to the definition of affordable housing, the maintenance and housing costs should not exceed 30% of the occupant's income. If the maintenance costs of the innovative technology exceed this amount, then the affordability of the house is no longer a factor. Hoínková (2021) argues that modular construction technology will be a cost-benefit for homeowners in the affordable housing bracket. Due to the flexibility of modular construction, homeowners can design a house that is smaller and fits their current income. If or when their household income rises and their family grows, they can easily expand their house similar to Lego blocks, giving them financial flexibility. However, it is worth considering that due to the "newness" of these technologies, it can be difficult to maintain them if there are fewer suppliers for innovative technologies compared to suppliers for brick and mortar. These few suppliers may also charge a notably high price if they have to repair something wrong in a 3D printed or modular house compared to a house made from brick and mortar.

2.7.6.3 The Costs of Innovative Technology:

These technologies can change the narrative of dropping overall production costs on paper. However, one factor that cannot be ignored is the initial expensive nature of these technologies. In a developing nation such as South Africa, introducing new technology in a cost-sensitive construction industry will always result in an increased capital outlay (Buchanan & Gardner, 2019; Mahachi, 2021). New technologies often have few or no suppliers, as a result, the fundamental economic principle states that the cost of the product will be significantly high, such as with 3D Printing. Not only will it be difficult to purchase a 3D Printer, but the cost of materials will also be more expensive than conventional building materials due to the lack of supply. In addition, technologies such as BIM, VR, AR, Unmanned Air Vehicles, and Modular Construction Assembly Plants are not cheap. It will be difficult for companies in the public sector to have the necessary capital to invest in these technologies for the development of affordable housing. Therefore, until the supply of new innovative technologies has increased in South Africa, it is difficult to see the positive effect these technologies will have on the affordability of affordable housing.

2.8 Exploring Innovative Technologies for Affordable Housing Delivery in South Africa

2.8.1 Object-Oriented Programming

Object-Oriented Programming (OOP) is a programming paradigm that revolves around the concept of objects, which are instances of classes that encapsulate data and the methods operating on that data (Asha Rani, et al., 2017). OOP languages, such as Java and C++, provide a framework for structuring code by organising it into modular and reusable components. The fundamental principle of OOP is to model real-world entities as objects, which can interact with each other to perform specific tasks. These objects possess properties (data) and behaviours (methods), allowing developers to design software systems that mimic real-world scenarios more effectively. The integration of OOP within the construction industry offers numerous advantages. For instance, OOP can be applied in the development of computer-aided design (CAD) software, enabling architects and designers to create detailed 3D models of houses with various design elements (Fernandes, 2019). By encapsulating the properties and behaviours of these design elements into objects, OOP allows for efficient modelling and visualisation of the final design. This approach facilitates collaboration, as multiple team members can work on different aspects of the design simultaneously. Additionally, OOP-based applications can be utilised for construction project management, enabling effective tracking of tasks, resource allocation, and progress monitoring (Fernandes, 2019). Such applications can enhance project efficiency, ensuring that construction projects, including affordable housing initiatives, stay on schedule and within budget (Santos, 2020).

2.8.1.1 Advantages of OOP adoption:

One of the key advantages of OOP is the reusability of code, which allows for the creation of modular components that can be used in multiple parts of a program (Marin, 2018). This promotes time and effort savings during software development, as developers can define objects once and utilise them throughout the program (Yilmaz, 2016). OOP also facilitates modular design, promoting good software organisation and making it easier to understand and modify code (Kim, 2015). This modular approach enhances collaboration among team members and improves the overall efficiency of the development process (Lee, 2016). Another advantage is the extensibility of OOP, which allows for the creation of new objects inheriting characteristics and behaviours from existing objects (Lopez, 2019). This feature enables the seamless addition of new features to a program, reducing the design time required for housing projects when using OOP-based applications. OOP also offers improved security by allowing designers to define access restrictions for data and methods within objects (Zhang, 2018). Additionally, OOP facilitates the creation of abstractions, simplifying complex systems by encapsulating data and methods within objects (Lopez, 2019). This abstraction enables a higher-level perspective, focusing on the interactions between objects rather than the intricate implementation details of individual components (Kim, 2015).

2.8.1.2 Disadvantages of OOP adoption:

One of the primary disadvantages of OOP is its complexity compared to other programming paradigms (Zhang, 2018). Working with objects requires a deeper understanding of programming concepts, making OOP more challenging to learn and use (Lee, 2016). Additionally, OOP can be more resource intensive as it involves the creation of additional objects and data structures (Santos, 2020). This can impact the overall performance and resource utilisation of the program. Another drawback is the lack of flexibility in OOP compared to other programming approaches (Brahman, 2017). OOP relies on a fixed set of objects and their interactions, which may limit adaptability to changing requirements.

Debugging OOP programs can also be more challenging due to the complexity of interactions between objects, making error tracing more difficult (Kim, 2015). Finally, initial costs may be higher when adopting OOP technology due to the need for specialised tools and the learning curve associated with implementing this programming paradigm (Mahachi, 2021).

2.8.1.3 OOP's Impact on Affordable Housing Delivery:

The impact of OOP on affordable housing delivery lies in its potential to enhance the efficiency and accuracy of the design and construction processes. OOP, when utilised in computer-aided design (CAD) software, allows architects and designers to create detailed 3D models of houses, incorporating various design elements (Fernandes, 2019). These 3D models provide a realistic visualisation of the final design, enabling stakeholders to make necessary changes and modifications before construction begins. For example, architects can use OOP to create parametric models where design variables, such as room dimensions, materials, and layouts, can be easily adjusted, allowing for quick exploration of design alternatives and optimisation of space utilisation (Santos, 2020). OOP supports the development of applications for construction project management, which can significantly contribute to affordable housing delivery. The modular nature of OOP allows for the creation of reusable code components, enabling the development of tailored project management tools. These tools can facilitate tasks such as progress tracking, budget management, and resource allocation (Fernandes, 2019). For instance, through the utilisation of OOP-based project management applications, construction companies can monitor construction progress in real-time, track expenses, and ensure efficient allocation of resources, thereby streamlining the delivery process of affordable housing projects. While OOP offers several advantages that can improve the delivery of affordable housing, it is important to consider the potential drawbacks as well. The complexity of OOP programming and the resources required for its implementation should be carefully weighed against the specific project's requirements and available resources. For example, the adoption of OOP may require additional training and expertise for professionals involved in the design and construction processes, and the development of OOP-based applications may necessitate significant investments in software development and maintenance. Therefore, it is crucial for construction companies to assess the cost-effectiveness and feasibility of adopting OOP in their affordable housing projects.

2.8.2 Project Portfolio Management

Project Portfolio Management (PPM) is a technology-driven approach that enables organisations to effectively manage a collection of projects, programs, and other work in alignment with strategic business objectives (PMI, 2017; Petit, 2012). It involves selecting and prioritising projects based on their potential returns and risks, optimising resource allocation, and enhancing stakeholder transparency and communication (Barbosa & Rodrigues, 2020). By aligning project portfolios with business strategies, PPM maximises shareholder value, improves decision-making, and enhances resource allocation and risk management (Barbosa & Rodrigues, 2020). Hiring a skilled project portfolio manager is crucial for successful PPM implementation as they facilitate effective communication and decision-making processes within the organisation (Jerbrant & Karrbom Gustavsson, 2013).

2.8.2.1 Advantages of PPM:

Implementing project portfolio management (PPM) processes in affordable housing projects offers several benefits. One key advantage is the ability to mitigate risks effectively. PPM dashboards enable the identification and proactive management of risks, ensuring timely project delivery and minimising potential delays (Lynn, 2022). By using PPM systems, construction companies can make informed decisions and provide stakeholders with clear data

to improve decision-making processes (Lynn, 2022). PPM helps identify bottlenecks, design flaws, and clarifies the scope of work for each team member, enhancing project coordination and workload management.

2.8.2.2 Disadvantages of PPM:

Despite its advantages, there are certain limitations to consider when implementing project portfolio management (PPM) processes. One limitation is the potential complexity and learning curve associated with PPM systems, requiring training and expertise for effective utilisation (Barbosa & Rodrigues, 2020). Additionally, the upfront investment in software implementation, infrastructure, and training costs can be substantial. Allocating resources and investing in skilled personnel to manage the PPM system effectively is necessary for its successful implementation. Organisational culture and change management also pose challenges, as stakeholder commitment and engagement are crucial for PPM's success.

2.8.2.3 PPM's Impact on Affordable Housing Delivery or Affordability:

Adopting project portfolio management (PPM) processes can have a profound impact on the delivery and affordability of affordable housing projects. PPM enables proactive risk management, which allows project teams to identify potential delays and implement measures to avoid them, thereby contributing to more efficient project delivery within the affordable housing sector. For example, through the implementation of PPM, project teams can assess the critical path of the project, identify potential bottlenecks, and allocate resources accordingly to ensure timely completion of construction milestones. The use of PPM provides clear data and insights that assist in informed decision-making, aligning projects with strategic goals and ensuring better financial outcomes. PPM systems offer stakeholders higher-level views of projects, allowing them to evaluate the overall project portfolio and make informed decisions regarding resource allocation, budgeting, and scheduling. For instance, PPM tools can provide real-time data on project progress, budget utilisation, and resource availability, enabling stakeholders to make timely adjustments and optimise the allocation of resources to maximise efficiency and cost-effectiveness (Lynn, 2022). PPM enhances collaboration and communication among project stakeholders, facilitating better coordination and reducing potential conflicts or misalignments (Barbosa & Rodrigues, 2020). By providing a centralised platform for project information and documentation, PPM systems streamline workflows, enable seamless information sharing, and enhance overall project transparency. This improves collaboration among various parties involved in affordable housing delivery, such as architects, contractors, suppliers, and regulatory authorities. The impact of PPM on the affordability of affordable housing projects is notable as well. By optimising project timelines, resource allocation, and risk management, PPM can help minimise project delays, cost overruns, and rework, leading to improved cost-effectiveness and affordability. The ability to track project progress, identify potential risks, and take corrective actions in a timely manner allows for better financial planning and control, ultimately contributing to the affordability of the housing units being delivered.

2.8.3 Building Information Modelling (BIM)

Building Information Modelling (BIM) is an innovative tool that has transformed the construction industry globally. It encompasses a set of policies, processes, and technologies that enable the management of essential building design and project data in digital format throughout the entire lifecycle of a building (Bryde, et al., 2013). BIM facilitates the creation of digital models that play a crucial role in the planning, design, construction, and operation stages of a project (Thurairajah & Goucher, 2013). However, the adoption of BIM in developing countries, including South Africa, faces challenges related to knowledge transfer,

a shortage of IT-literate personnel, and limited government support or contractual mandates (Bui, et al., 2016; Wortmann, et al., 2016). Despite these obstacles, the implementation of BIM can yield numerous benefits, including improved scheduling, enhanced design accuracy, streamlined facility management, effective collaboration among project stakeholders, and enhanced project visualisation (Bui, et al., 2016). By leveraging the capabilities of BIM, the construction industry can achieve greater workflow efficiency, accuracy, and overall project success.

2.8.3.1 Advantages of using BIM:

The implementation of Building Information Modelling (BIM) in affordable housing projects offers several advantages. Effective collaboration, scheduling, communication, project visualisation, coordination, and clash detection are identified as key benefits (Thurairajah & Goucher, 2013; Farnsworth, et al., 2015). Stakeholders in the construction industry recognise BIM as a tool that improves task efficiencies, reduces construction costs through reduced working hours, and minimises on-site rework (Farnsworth, et al., 2015). The findings presented by Farnsworth et al. (2015) in Figure 2.4. reveals that BIM offers a plethora of key benefits that have been widely recognised by industry professionals, revolutionising traditional construction practices. Firstly, BIM greatly enhances communication among developers, fostering seamless collaboration and information sharing throughout the project lifecycle. This leads to improved coordination, streamlined workflows, and reduced errors and conflicts during construction. BIM also contributes to the improvement of scheduling accuracy, enabling precise sequencing of tasks and resource allocation. With its advanced simulation capabilities, BIM empowers project teams to optimise construction sequences, minimise downtime, and ensure timely project completion. Another key advantage is BIM's ability to better facilitate coordination among the relevant stakeholders. In addition, BIM offers heightened visualisation capabilities for clash detection in designs. These attributes of BIM contribute to its immense value when employed by industry professionals, further solidifying its potential impact in the affordable housing sector.

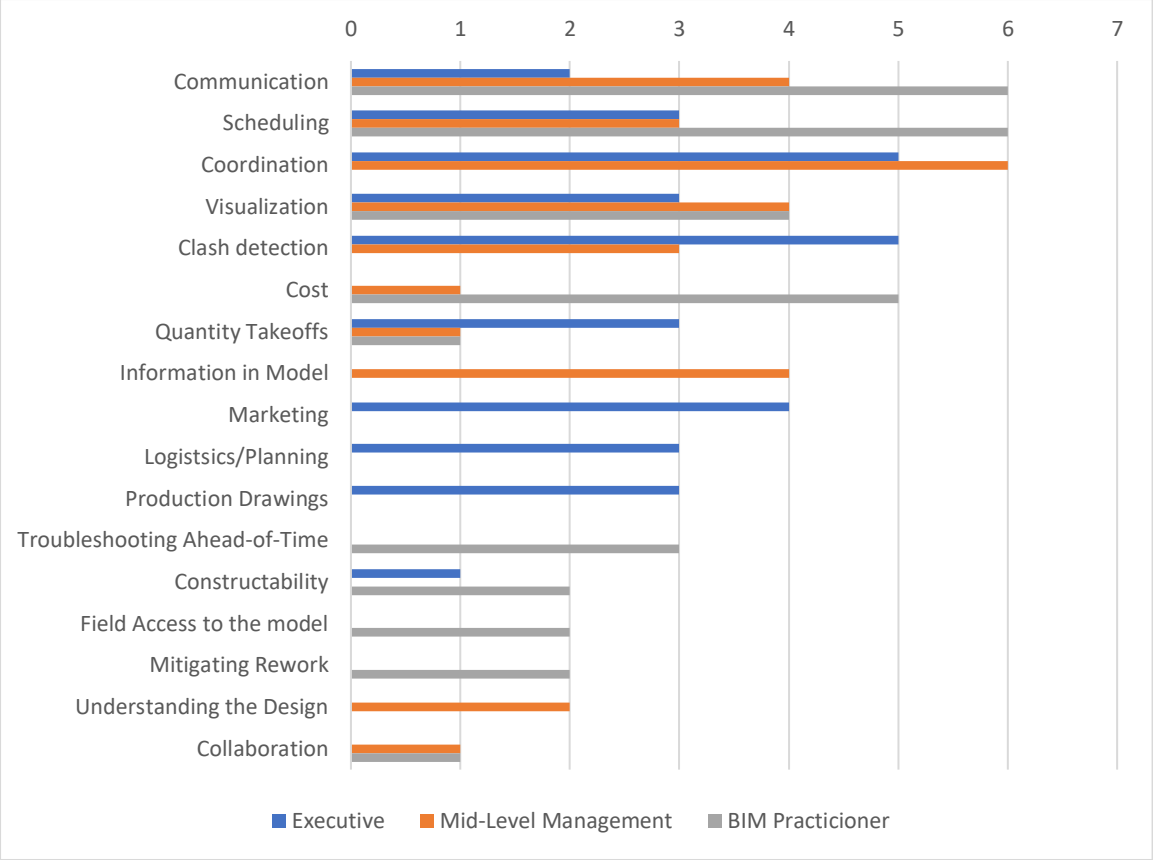


Figure 2.4 The combined advantages of using BIM (Farnsworth, et al., 2015)

Effective communication is enhanced through BIM's collaborative environment, enabling seamless information exchange and improved coordination among project (Thurairajah & Goucher, 2013). This streamlines decision-making processes, minimises misinterpretations, and fosters better collaboration, leading to improved project outcomes. BIM also revolutionises project scheduling by enabling detailed time-based simulations and sequencing of construction activities (Farnsworth, et al., 2015). It provides a visual representation of the project timeline, facilitating effective planning, resource allocation, and progress monitoring. By identifying potential clashes or conflicts between various building components, BIM helps mitigate errors and conflicts during the construction phase, resulting in substantial cost savings and reduced rework (Farnsworth, et al., 2015). Moreover, BIM's visualisation capabilities enable stakeholders to visualise and assess the project before construction, aiding in the early detection of design flaws, design optimisation, and improved decision-making.

Overall, the advantages of BIM in affordable housing projects are multidimensional, encompassing improved communication, enhanced scheduling, effective coordination, enhanced visualisation, clash detection, and cost management. These benefits not only contribute to improved project outcomes but also foster greater efficiency, accuracy, and cost-effectiveness in the delivery of affordable housing.

2.8.3.2 Disadvantages of BIM:

The implementation of BIM in developing nations like South Africa presents several disadvantages stemming from limited government support, lack of client knowledge, and minimal contractual enforcement (Liu, et al., 2015; Wortmann, et al., 2016). These disadvantages manifest as legal, contractual, technical, technological, organisational, and human factors that impede the successful integration of BIM (Wortmann et al., 2016). The

absence of robust government support can be addressed by mandating legislative standards and specifications for BIM, thereby encouraging construction companies and clients to adopt the technology through contractual agreements (Wortmann et al., 2016). Additionally, uncertainties surrounding stakeholder responsibilities, intellectual property, copyright, and data ownership can be mitigated by clearly defining these aspects in the contracts (Smith, 2014). Technical challenges arise from the transition from traditional design methods, lack of technological support, and concerns about the potential loss of intuitive creative thinking (Wortmann, et al., 2016; Gerges, et al., 2016). Organisational and human barriers include initial adoption costs, resistance to change, training requirements, and the absence of standardised curricula and specifications (Smith, 2014; Wortmann, et al., 2016; Gerges, et al., 2016) Overcoming these disadvantages necessitates revising educational curricula, providing comprehensive training programs, and fostering a transformation within the construction sector to cultivate digitally educated professionals (Wortmann et al., 2016).

2.8.3.3 Impact of BIM on Affordable Housing Delivery:

The adoption of Building Information Modelling (BIM) in affordable housing projects has the potential to revolutionise the construction process, offering a range of benefits that directly impact project delivery. BIM's impact on affordable housing is evident in key areas such as 3D visualisation, clash detection, reduced redundancy, improved information flow, and minimised time and cost (Moghayedi, et al., 2023). One significant impact of BIM in affordable housing is its ability to enhance project management. By providing a digital representation of the building throughout its lifecycle, BIM facilitates efficient coordination and communication among stakeholders including architects, engineers, contractors, and suppliers. This collaborative approach reduces misunderstandings, minimises rework, and ensures alignment towards common project objectives (Farnsworth, et al., 2015). Additionally, BIM streamlines the measurement process, enabling faster and more accurate quantity extraction, thus minimising redundant work. Effective management of information flow and utilisation of BIM across the project lifecycle contribute to improved efficiency and cost savings (Moghayedi, et al., 2023). For instance, BIM's impact on clash detection is noteworthy. By identifying and resolving conflicts between different design elements before construction commences, BIM eliminates costly and time-consuming rework. Furthermore, BIM enables cost reduction in affordable housing projects. Its digital representation allows for accurate quantity take-offs, material estimation, and identification of cost-saving opportunities. Through optimised material usage and waste reduction, BIM can lead to significant cost savings during construction (Thurairajah & Goucher, 2013). Precise estimation of construction material quantities helps avoid over-ordering and excess inventory, promoting cost efficiency.

Improved collaboration is another key impact of BIM on affordable housing delivery. The shared digital platform of BIM enables real-time collaboration and information exchange among stakeholders. This fosters effective communication, reduces delays, and enhances decision-making capabilities (Farnsworth, et al., 2015). For example, architects and engineers can work collaboratively on a virtual model, making simultaneous modifications and sharing feedback. This streamlined collaboration expedites the design process and ensures that all parties are aligned, resulting in a more efficient and synchronised construction process. Visualisation is also enhanced through the utilisation of BIM. With BIM technology, stakeholders can experience a realistic and immersive visual representation of the project. This visual clarity improves understanding, reduces ambiguity, and allows for better-informed decision-making at every stage of the project (Gerges, et al., 2016). For instance, potential buyers or investors can virtually explore the affordable housing units before they are constructed, providing them with a realistic sense of the space and design. This visualisation

capability enhances marketing efforts and helps to build trust and confidence in the project. The biggest challenge is that the drivers of BIM adoption are identified as owner/client involvement, utilisation by contractors, and utilisation by consultants. The active participation of owners/clients, both in the public and private sectors, is crucial in driving BIM adoption and reaping its benefits (Moghayedi, et al., 2023).

2.8.4 Geographic Information System (GIS)

Geographic Information Systems (GIS) is a computer system that captures, stores, checks, and displays data related to positions on Earth's surface. It is a powerful tool for understanding spatial patterns and relationships by utilising location-based information such as latitude, longitude, address, or ZIP code. The components of a GIS platform include hardware, software, spatial data, and a system manager, which together process and analyse heterogenous data to uncover trends, patterns, and relationships (Amin & Noori, 2016; National Geographic, 2022; Zhu, et al., 2018). According to Windapo and Moghayedi (2017), GIS provides developers with a powerful tool for visualising, querying, analysing, and interpreting data in order to gain insights into relationships, patterns, and trends. Essentially, GIS represents data in a 2D, or 3D format, providing a comprehensive view of topographic information encompassing natural and man-made features of the world (Lu, et al., 2017; Zhu, et al., 2018). Figure 2.5 illustrates the types of data that can be captured by GIS technology, ranging from street data to building data, vegetation, and integration of all the data to give an overarching view of the topographic information presented by GIS technology.

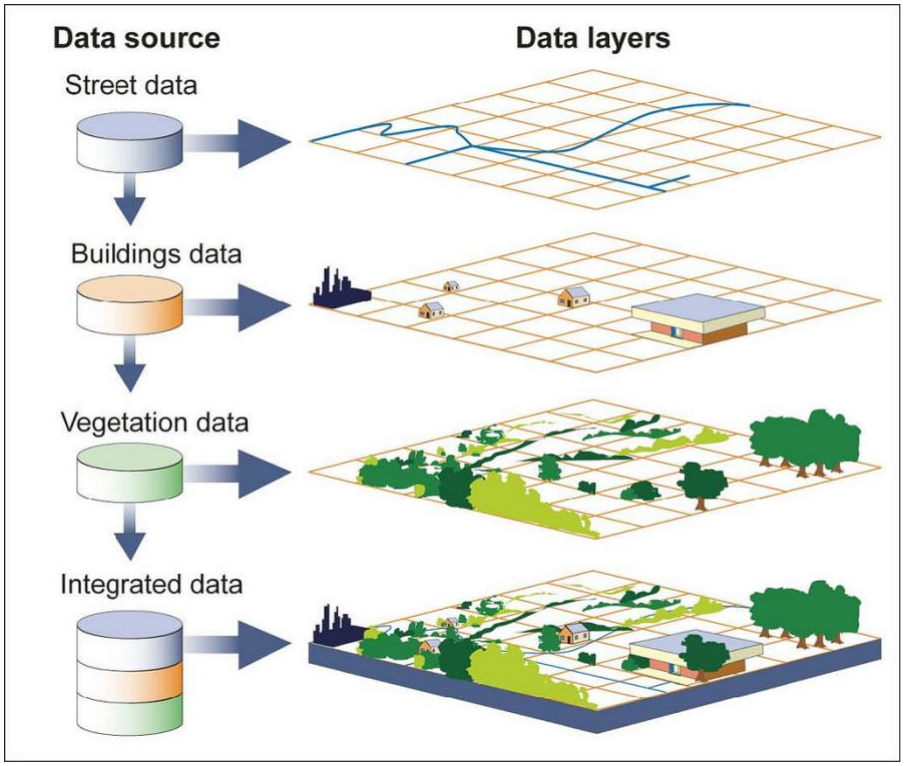


Figure 2.5 Illustration of data layers captured by the GIS technology (National Geographic, 2022)

2.8.4.1 Advantages of GIS:

GIS technology offers numerous benefits, including the ability to collect and analyse data on specific population groups, detailed landscape information, and infrastructure data within an area (National Geographic, 2022). It enables better decision-making by providing insights into

spatial relationships, facilitating efficient resource allocation, and aiding in emergency response planning (Amin & Noori, 2016; National Geographic, 2022). Additional research findings suggest that GIS can be utilised to identify geographical areas characterised by variations in building material prices. This information can then be leveraged to explore cost-effective infrastructure projects and propose alternative innovative construction technologies as potential solutions (Windapo & Moghayedi, 2017). The integration of GIS with other technologies, such as Building Information Modelling (BIM), enhances its capabilities in areas such as indoor network analysis, noise assessment, flood impact analysis, and smart city planning (Amirebrahimi, et al., 2016; Di Giulio, et al., 2017; Teo & Cho, 2016). Furthermore, GIS can contribute to minimising construction waste and improving construction process events such as site selection, safety management, and environmental impact assessment (Blengini & Garbarino, 2010; Lu, et al., 2017).

2.8.4.2 Disadvantages of GIS:

The utilisation of Geographic Information Systems (GIS) in the construction industry offers numerous advantages, but it is not without its limitations. One key disadvantage is the relatively limited 3D modelling and editing capabilities of GIS software compared to more advanced tools like Building Information Modelling (BIM) (Zhu, et al., 2018). While GIS can interpret 2D drawings and generate 3D models, the editing functions available are often restricted. This limitation hinders the ability to perform complex modifications and detailed editing tasks within the GIS environment. However, this drawback can be mitigated by integrating GIS with BIM, which provides more advanced 3D modelling and editing functionalities (Zhu, et al., 2018). Another challenge associated with GIS implementation is the need for data interoperability and standardisation. The integration of spatial data from various sources can be complex and requires careful attention to data formats, coordinate systems, and data quality. Inconsistencies or incompatibilities among different datasets can lead to errors and inaccuracies in the GIS analysis (Lu, et al., 2017). Additionally, the management and maintenance of vast amounts of spatial data can be demanding, requiring adequate resources, technical expertise, and robust data management systems. The lack of data standardisation and interoperability can pose challenges for organisations seeking to implement GIS effectively.

2.8.4.3 Impact of GIS on Affordable Housing Delivery and Affordability:

Where GIS will be the most impactful in affordable housing's delivery process or affordability is with the integration of GIS and BIM. By combining the spatial data capabilities of GIS with the rich information modelling of BIM, stakeholders in the construction industry can make more informed decisions and optimise various aspects of affordable housing projects. (Amirebrahimi, et al., 2016). One area where GIS can make a significant impact is in site selection for affordable housing developments. GIS can provide valuable insights into factors such as proximity to amenities, transportation infrastructure, and social services (Amin & Noori, 2016). By analysing spatial data on these factors, decision-makers can identify optimal locations for affordable housing projects that meet the needs of the target population while considering factors like accessibility and affordability. GIS can support environmental impact assessment in affordable housing projects. By incorporating spatial data on ecological features, land use patterns, and environmental regulations (National Geographic, 2022), GIS enables the evaluation of potential environmental impacts during the development process. This information can inform design choices, resource allocation, and mitigation strategies to minimise the ecological footprint of affordable housing projects. This can avoid costly methods of mitigating these issues only after discovering these environmental impacts have been violated. By transferring geometric and semantic information from BIM to a "geospatial context," GIS can play a crucial role in improving the efficiency and effectiveness of affordable

housing projects. It enables informed decision-making, aids in resource allocation, and enhances the understanding of the spatial aspects of housing development, ultimately contributing to improved affordability and delivery outcomes (Lu, et al., 2017).

2.8.5 Smart Sensors

Smart sensor technologies represent an advancement in sensory technologies, designed to extract data from the physical environment. These devices use built-in systems to analyse and process the collected data before transmitting it to the intended destination. Smart sensors can sense various parameters such as heat, light, vibrations, or pressure, converting the analogue signals into digital data for further use (Posey, 2022). With their capabilities, smart sensors have found practical applications in the construction industry, offering valuable benefits and functionalities.

2.8.5.1 Advantages of Smart Sensors:

Smart sensors offer several advantages in construction projects. They can detect process "drift" and help site managers identify the next milestones and phases of construction, ensuring project schedule efficiency (Nichols, 2020). By monitoring vibrations and sounds, smart sensors placed on critical machinery enable proactive maintenance, minimising the risk of machinery failure and optimising project timelines. These sensors also provide real-time data visibility to stakeholders, regardless of their location, facilitating informed decision-making and enhancing project communication. Additionally, smart sensors enable automatic asset tracking on construction sites, reducing the chances of lost or stolen materials and equipment. Moreover, wearable smart sensory devices incorporating smart sensors can enhance construction safety by monitoring workers' vitals and ensuring compliance with health and safety protocols (Nichols, 2020).

2.8.5.2 Disadvantages of Smart Sensors:

While smart sensors offer significant advantages, there are also some limitations to consider. One challenge is the potential complexity of integrating smart sensors into existing construction workflows and systems, which may require adaptations and changes to ensure seamless data collection and utilisation. Additionally, there may be upfront costs associated with implementing smart sensor technologies, including the purchase of sensors, installation, and maintenance (Nichols, 2020). Moreover, ensuring data security and privacy in the context of smart sensors is crucial, as the collected data may include sensitive information that needs to be protected.

2.8.5.3 Smart Sensors Impact on Housing Delivery and Affordability:

The integration of smart sensors in affordable housing projects offers numerous opportunities to improve the delivery process and enhance affordability. One key area where smart sensors can have a significant impact is project schedule optimisation. By leveraging real-time data from smart sensors, construction teams can closely monitor the progress of various construction milestones. This enables early detection of potential delays or bottlenecks, allowing project managers to take proactive measures to address issues and keep the project on track (Nichols, 2020). For example, if there is a delay in a particular construction activity, smart sensors can alert project managers, enabling them to allocate additional resources or adjust the construction schedule accordingly to minimise the impact on overall project timelines. In addition to schedule optimisation, smart sensors can also play a crucial role in materials and equipment management. The automatic asset tracking capability of smart sensors can help prevent the loss of materials and equipment, mitigating financial losses and ensuring smooth project progress.

Furthermore, the use of wearable smart sensory devices for construction workers can enhance safety measures and compliance with health and safety regulations, reducing the likelihood of accidents and related expenses (Nichols, 2020).
The use of wearable smart sensory devices for construction workers can significantly enhance safety measures on affordable housing construction sites. These devices can monitor factors such as worker movements, body temperature, and exposure to hazardous conditions (Nichols, 2020). By collecting and analysing this data in real-time, smart sensors can help identify potential safety risks and alert both workers and supervisors to take necessary precautions. This proactive approach to safety management reduces the likelihood of accidents and injuries, minimising the associated financial costs and potential project delays. The integration of smart sensors with energy management systems can contribute to the overall affordability of affordable housing. Smart sensors can monitor and regulate energy usage in housing units, optimising energy efficiency, and reducing utility costs for residents (Nichols, 2020). By automatically adjusting lighting, heating, and cooling systems based on occupancy and environmental conditions, smart sensors help minimise energy waste and ensure that energy consumption aligns with actual needs. This translates into lower energy bills for residents, improving the long-term affordability of affordable housing units.

2.8.6 Virtual Reality

Virtual Reality (VR) is a technology that creates immersive and interactive experiences for users by using synthetic and virtual methods. It allows individuals to perceive and interact with a simulated environment as if they are present within it. VR systems are designed to provide a sense of presence, allowing users to explore and engage with virtual environments through the use of specialised devices such as Head Mounted Displays (HMDs) and audio-haptic devices (Shen & Shirmohammadi, 2008; Cipresso, et al., 2018). By simulating real-world scenarios, VR technology offers a unique opportunity for construction professionals to visualise and analyse projects before they are built, improving communication, collaboration, and efficiency throughout the design and construction process.

2.8.6.1 Advantages of VR:

The usage of VR in construction brings several advantages. Firstly, it enables realistic and immersive visualisation of building designs, allowing stakeholders to gain a better understanding of the project and make informed decisions (Sharifi, 2018). VR technology facilitates enhanced collaboration and communication among team members, enabling them to identify errors, ask questions, and make real-time decisions within the virtual environment (Sharifi, 2018; Cerga, 2022). VR can also streamline the design process by providing a real feel of the building, improving scalability and accuracy (Brooks, 2022; Sharifi, 2018). It helps in reducing delays and rework by detecting potential issues early on and avoiding costly modifications during the construction phase (Brooks, 2022; Baeza, 2018). Additionally, VR enhances client satisfaction by offering immersive experiences and enabling clients to visualise their projects in detail (Sharifi, 2018; Cerga, 2022).

2.8.6.2 Disadvantages of VR:

While VR technology offers significant benefits, there are challenges associated with its adoption in the construction industry. Limited updates and support specifically tailored to the construction industry's needs hinder the utilisation of the latest advancements in VR technology (Baeza, 2018). The slow adoption of innovative technologies within the construction industry itself contributes to the slower uptake of VR (Baeza, 2018). Limited software integration and technical support for VR components in construction software can lead to inefficiencies and

delays (Baeza, 2018). Moreover, the cost of implementing VR systems, especially for small and medium-sized enterprises, may pose a barrier to widespread adoption (Baeza, 2018).

2.8.6.3 VR's Impact on Affordable Housing Delivery and Affordability

The application of VR technology in affordable housing projects has the potential to bring significant benefits to the delivery process and affordability. One key impact of VR is its ability to provide realistic visualisations of designs, allowing stakeholders to experience and interact with virtual representations of the proposed housing units (Brooks, 2022). This immersive experience enables developers and construction teams to optimise the use of resources by identifying potential design flaws or spatial inefficiencies before the construction phase. By catching these issues early on, costly rework and modifications can be minimised, resulting in cost savings and improved project efficiency. VR facilitates better collaboration and communication among project stakeholders, including architects, engineers, contractors, and clients (Sharifi, 2018). Through virtual walkthroughs and simulations, all parties can gain a shared understanding of the project, identify any discrepancies or conflicts, and make informed decisions in a collaborative manner. This reduces the likelihood of miscommunication or misunderstandings, leading to fewer errors and rework during construction. By minimising rework and ensuring that construction progresses smoothly, VR contributes to cost-effective project delivery in the affordable housing sector.

Another significant impact of VR is its potential to empower clients and improve their decision-making process. By experiencing virtual walkthroughs of housing designs, clients can visualise the final product and better understand the spatial layout, finishes, and overall aesthetic appeal (Cerga, 2022). This immersive experience enables clients to make more informed decisions and provide valuable feedback during the design phase, reducing the need for costly design changes later in the construction process. Additionally, VR can facilitate virtual customisation options, allowing clients to visualise different design choices and make selections that align with their preferences and budget. This level of client involvement and satisfaction contributes to more profitable outcomes and enhances the affordability of affordable housing projects. However, an important consideration are the initial costs of implementing VR systems which could pose a challenge to its widespread adoption in affordable housing projects, especially in smaller-scale developments (Baeza, 2018). The cost of VR hardware, software, and specialised expertise may be a barrier for some developers, limiting its application to larger projects or those with more significant financial resources. Nevertheless, as technology advances and becomes more accessible, the cost of VR implementation is expected to decrease, making it a more feasible option for affordable housing developments in the future.

2.8.7 Augmented Reality

Augmented Reality (AR) is a technology that enhances the real-world environment by overlaying computer-generated information in a real-time manner (Shen & Shirmohammadi, 2008). AR builds upon the principles of Virtual Reality (VR) by adding virtual objects to the real world, providing users with an interactive and immersive experience (Cipresso, et al., 2018). Key components of AR technology include a geospatial datum for virtual objects, visual markers to determine object position, and sufficient processing power for graphics and animation (Cipresso, et al., 2018). AR devices are typically worn by users and can range from glasses with a camera display to other forms of headsets or mobile devices that track user movement (Azuma, et al., 2001).

2.8.7.1 Advantages of AR:

AR technology offers numerous advantages for the construction industry. It has the potential to transform project planning, communication, collaboration, safety, and training (Ellis, 2022).

Through AR, stakeholders can visualise and comprehend project plans more effectively, reducing the risk of errors and rework (Ellis, 2022). Progress capture using AR enables remote project monitoring, helping project managers stay on schedule and address any issues promptly (Ellis, 2022). AR also enhances collaboration among team members, allowing for effective communication and identification of potential errors (Ellis, 2022). In terms of safety, AR can provide real-time information about safety hazards, increasing worker awareness and minimising risks (Ellis, 2022). Additionally, AR facilitates construction training by offering life-like simulations, helping workers understand complex equipment and innovative building technologies (Ellis, 2022).

2.8.7.2 Disadvantages of AR:

The adoption of AR in the construction industry faces several challenges. These include the cost of implementation, immaturity of the technology, lack of standardisation in AR applications, uncertainty about the value and benefits of the technology, and the need for skilled personnel (Heinzel, et al., 2017; Nassereddine, et al., 2022; Viljakainen, 2020). Technical issues, maintenance costs, and a fragmented nature within the construction industry also present barriers to AR adoption (Nassereddine, et al., 2022). Overcoming these challenges requires ongoing technological advancements, standardisation efforts, training programs, and a shift in organisational culture to embrace change (Nassereddine, et al., 2022; Viljakainen, 2020).

2.8.7.3 Impact of AR on Affordable Housing Delivery

The application of AR technology in affordable housing projects has the potential to significantly impact the delivery process and affordability. One key impact of AR is its ability to enhance project planning and visualisation. By overlaying digital information onto the physical environment, AR enables stakeholders to visualise and assess the proposed housing designs in real-time (Ellis, 2022). This immersive experience allows for better decision-making, as stakeholders can identify design flaws, spatial inefficiencies, or potential clashes before construction begins. By addressing these issues early on, costly errors, rework, and delays can be minimised, leading to more efficient resource utilisation and improved project timelines. Additionally, AR enhances communication and collaboration among project stakeholders, including architects, engineers, contractors, and clients. By using AR-enabled devices, all parties can view and interact with 3D models, virtual annotations, and project information in real-time (Ellis, 2022). This shared visualisation promotes better understanding and alignment, reducing the likelihood of miscommunication or misunderstandings. Stakeholders can collaborate more effectively, make informed decisions, and provide valuable feedback during the design and construction phases. This improved communication and collaboration contribute to more efficient and streamlined construction processes, ultimately enhancing affordability. Another significant impact of AR is its potential to enhance construction training and safety. AR technology can provide interactive and immersive training experiences for construction workers, allowing them to familiarise themselves with complex equipment, safety protocols, and innovative construction technologies (Ellis, 2022). By using AR-enabled devices, workers can access real-time instructions, visual aids, and step-by-step guidance, reducing the likelihood of errors and accidents. These enhanced training and safety measures contribute to improved productivity, minimised waste, and reduced project costs, ultimately benefiting the affordability of housing projects. While challenges may exist, such as the need for specialised hardware and expertise, the potential benefits of AR adoption in affordable housing delivery make it a technology worth considering for the construction industry. The optimisation of resources, improved collaboration and visualisation capabilities, enhanced training, and improved safety measures offered by AR contribute to more efficient

and cost-effective construction processes. As AR technology continues to advance and become more accessible, the barriers to adoption are expected to decrease, making it a valuable tool for enhancing the affordability of affordable housing projects.

2.8.8 3D Laser Scanners

3D laser scanning is a technology that utilises laser beams to capture millions of measurements of an object or space, generating a point cloud in a 3D coordinate system (Almukhtar, et al., 2021). This process allows for accurate mapping and detailed data collection, making it valuable for various applications in architecture, engineering, and construction (AEC) fields (Pärn & Edwards, 2017). The combination of high precision and efficiency enables the creation of comprehensive representations of complex structures, facilitating project management throughout all stages of a construction project.

2.8.8.1 Advantages of 3D Laser Scanners:

The utilisation of 3D laser scanners offers numerous advantages for stakeholders in the construction industry. The exceptional accuracy and precision of these scanners allow for the capture of highly detailed point clouds, detecting even small variations in measurements (Fröhlich & Mettenleiter, 2004; Sanhudo, et al., 2020). This level of accuracy enhances the understanding of scanned areas and enables effective quality assessment. Additionally, 3D laser scanners are well-suited for capturing data from intricate structures where traditional measurement methods may be impractical or impossible. This makes them valuable for scanning historical buildings, bridges, and machinery (Fröhlich & Mettenleiter, 2004; Sanhudo, et al., 2020).

2.8.8.2 Disadvantages of 3D Laser Scanners:

Despite their advantages, 3D laser scanners have certain limitations and challenges. One major limitation is the high cost of the equipment, making them a significant investment for construction companies (Arayici, et al., 2006). The process of scanning and generating 3D models from point clouds can also be time-consuming and require specialised software and expertise, leading to higher labour costs and longer project timelines. Furthermore, the physical size and weight of the equipment can make it difficult to use in tight or confined spaces, posing challenges for scanning in affordable housing projects. These factors should be carefully considered before implementing 3D laser scanners in construction projects (Arayici, et al., 2006).

2.8.8.3 Impact of 3D Laser Scanners on Affordable Housing Delivery

The impact of 3D laser scanners on affordable housing delivery lies in their ability to improve project management, quality assessment, and data collection. By capturing accurate measurements and generating detailed point clouds, 3D laser scanners can support efficient construction processes and enhance the overall quality of housing projects. The technology enables precise documentation of existing conditions, aiding in design and renovation processes. However, the high cost of equipment and specialised expertise required for data processing can pose challenges, particularly for smaller construction companies involved in affordable housing projects (Arayici, et al., 2006). Careful evaluation of the benefits and limitations is essential to determine the feasibility and impact of implementing 3D laser scanning technology in the context of affordable housing delivery.

2.8.9 Artificial Intelligence

Artificial intelligence (AI) is a field of computer science focused on creating machines that can think and act like humans. It involves replicating the synapses of a human brain in artificial neural networks, enabling machines to engage in critical appraisal, decision-making, and learning from previous data (Dick, 2019; Rao, 2022). AI is a powerful tool that integrates information, analyses data, and enhances decision-making processes across various industries.

2.8.9.1 Artificial Intelligence Advantages:

The integration of AI strategies in the construction industry offers numerous benefits. AI can address challenges related to safety concerns, labour shortages, cost overruns, and schedule delays (Rao, 2022). By leveraging AI technologies, construction projects can benefit from improved cost estimation and predictive analysis, enabling better project planning and risk mitigation (Rao, 2022). AI also facilitates generative design, enhancing the creation of optimised designs and identifying clashes (Rao, 2022). Additionally, AI integration in construction machinery enables the development of self-driving vehicles that can automate repetitive tasks, increasing productivity and reducing labour shortages (Rao, 2022).

2.8.9.2 Disadvantages of Artificial Intelligence:

Despite its advantages, AI implementation in construction faces certain challenges. One significant drawback is the limited knowledge and understanding of AI among senior business leaders, which hinders its effective implementation in organisations (Davenport, et al., 2017). Additionally, AI integration can be costly, requiring investments in hardware, software, and specialised expertise (Rao, 2022). The complexity of AI systems and the need for continuous updates and maintenance pose additional challenges for construction companies. Furthermore, concerns regarding data privacy and security may arise with the use of AI technologies (Rao, 2022).

2.8.9.3 Impact Artificial Intelligence Has on Affordable Housing Delivery:

The application of AI in affordable housing projects has the potential to revolutionise the delivery process and enhance affordability. One key impact of AI is its ability to improve project management. AI systems can analyse vast amounts of data, identify patterns, and make accurate predictions, enabling more effective cost estimation and project planning (Rao, 2022). By leveraging AI algorithms, affordable housing projects can benefit from optimised designs, precise cost projections, and improved resource allocation, ultimately leading to more efficient and cost-effective construction processes. AI can also play a crucial role in risk mitigation. By utilising AI-powered systems, project teams can identify and prioritise potential risks and develop proactive strategies to mitigate them (Rao, 2022). This predictive capability allows for early intervention and effective risk management, reducing the likelihood of costly delays and unexpected expenses. Additionally, AI can contribute to enhanced productivity in affordable housing projects. Automation and AI integration in construction machinery can mitigate labour shortages and increase overall productivity (Rao, 2022). Using AI-powered tools and equipment, tasks can be performed with greater efficiency and accuracy, resulting in shorter construction timelines and reduced costs. In addition, AI can significantly impact the manufacturing and delivery of affordable housing components. Offsite construction and modular factories equipped with AI systems can optimise production processes, ensuring precise fabrication and timely delivery of building components (Rao, 2022). AI can analyse data on material usage, production schedules, and quality control, enabling more efficient operations and minimising waste. By streamlining the manufacturing process, AI contributes to cost reduction, improved quality, and faster assembly of affordable housing units. While the adoption of AI in affordable housing may come with its challenges, such as initial investment

costs and the need for skilled personnel, the potential benefits it offers for delivery and affordability are substantial. The ability of AI systems to optimise project management, enhance cost estimation, mitigate risks, improve productivity, and streamline manufacturing processes makes it a promising technology for the affordable housing sector.

2.8.10 Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAVs), commonly known as drones, have become a significant addition to the construction industry, transforming data capture and monitoring processes (Asadi, et al., 2020). These technological devices offer superior accuracy, efficiency, and cost-effectiveness on construction sites (Greenwood, et al., 2019). UAVs are particularly beneficial for detailed inspections, precise surveying, and mapping in construction projects (Tkáč & Mésároš, 2019). With their aviation capabilities, UAVs provide unique advantages for addressing construction activities, leading to a significant increase in their usage within the industry.

2.8.10.1 Advantages of UAVs

Despite the limited empirical studies on the benefits of UAVs in construction, researchers have explored various potential applications and advantages. The use of UAVs in construction can lead the industry toward digitalisation and automation, improving building surveys, topographic mapping, and land surveys (Tkáč & Mésároš, 2019). Technologies such as UAVs provide the end user with improved and safe work conditions which is a direct link towards increased site safety and reduced costs on site due to minimal health threats (Massyn, et al., 2022). In addition, UAVs facilitate construction site inspections, equipment tracking, and remote monitoring, enabling real-time progress reports (Tkáč & Mésároš, 2019). UAVs also offer capabilities for laser scanning, aerial photogrammetry, and thermal imaging recording, expanding the range of data collection and analysis methods available to the industry (Tkáč & Mésároš, 2019). The implementation of these technologies undoubtedly yields positive gains in construction project implementation and performance, a fact supported by scholars worldwide (Massyn, et al., 2022).

2.8.10.2 Disadvantages of UAVs:

While UAVs bring significant advantages, there are certain drawbacks to consider. The limited empirical research specifically focusing on UAVs in the construction industry poses challenges in fully understanding and utilising their potential benefits (Elghaish, et al., 2021). Additionally, regulatory restrictions and compliance with aviation laws and regulations can limit the operational flexibility and usage of UAVs on construction sites (Tkáč & Mésároš, 2019). Privacy concerns may also arise due to the aerial surveillance capabilities of UAVs, requiring careful consideration and adherence to privacy protocols.

2.8.10.3 Impact of UAVs on Affordable Housing Delivery

The application of UAVs in affordable housing projects can have a significant impact on the delivery process and affordability. UAVs offer a range of benefits that improve efficiency, accuracy, and cost-effectiveness in construction processes. One key impact of UAVs is their ability to streamline data capture, surveying, and monitoring activities. UAVs equipped with high-resolution cameras and sensors can capture aerial imagery and collect data more efficiently compared to traditional methods (Greenwood, et al., 2019). This enables faster and more accurate site surveys, allowing for more precise project planning and execution. By using UAVs for data collection, affordable housing projects can reduce costs associated with manual surveys and enhance the overall project timeline. The use of UAVs in construction contributes

to improved quality control and safety management. UAVs can perform regular inspections and monitor construction sites, identifying potential safety hazards and quality issues (Irizarry & Costa, 2016). This proactive approach to monitoring enhances safety on-site and reduces the risk of accidents, which can result in cost overruns and delays. Additionally, UAVs can automate certain tasks, such as aerial mapping and data collection, reducing the need for manual labour and increasing productivity (Tkáč & Mésároš, 2019). This automation saves time and resources, contributing to cost-effectiveness in the construction process. The availability of detailed aerial data and insights provided by UAVs also supports informed decision-making in affordable housing projects. The collected data can be used to generate 3D models, perform volume calculations, and analyse site conditions (Greenwood, et al., 2019). This information helps project teams make more accurate and informed decisions regarding resource allocation, construction strategies, and design modifications. By optimising these decisions, affordable housing projects can achieve greater efficiency and cost-effectiveness, ultimately enhancing affordability. While the adoption of UAVs in affordable housing projects offers significant benefits, it is essential to consider potential challenges, such as regulatory requirements, pilot training, and data management. Compliance with airspace regulations and obtaining necessary permits are important considerations when utilising UAVs. Ensuring proper training for operators and implementing robust data management processes are also crucial for maximising the potential of UAV technology in affordable housing delivery.

2.8.11 Modular Construction

Modular construction is a technology that involves fabricating major building components offsite in a factory and transporting them to the construction site for assembly (Delux Modular, 2019). This approach offers advantages such as faster construction, safer manufacturing environments, and enhanced quality control (Thai, et al., 2020). It can be classified into 2D panelised systems and 3D volumetric solutions, both of which allow a significant portion of the building to be prefabricated offsite (Mortice, 2019).

2.8.11.1 Advantages of Modular Construction:

Modular construction offers several significant advantages. Firstly, it enhances the quality of buildings through effective production processes and quality control during offsite component manufacturing. By incorporating robotics and artificial intelligence, modular construction ensures accurate designs and thorough quality control, meeting, or exceeding building regulations (Rao, 2022). Secondly, it provides design flexibility for both homeowners and architects. Homeowners can customise the design of their modular homes based on their financial situation, adjusting the size of their homes to fit their mortgage rates. Additionally, architects benefit from the design flexibility of modular construction, as it allows them to create innovative structures in various shapes and forms that are easier for construction workers to assemble (Hoínková, 2021). Lastly, modular construction enables faster delivery time. By moving the construction process to a controlled factory environment, components such as walls, ceilings, and roofs can be manufactured simultaneously and quickly assembled on-site, reducing construction times by up to 50% (Hoínková, 2021).

2.8.11.2 Disadvantages of Modular Construction:

Despite its advantages, modular construction also presents certain challenges. One disadvantage is the complexity of transportation methods. The size and shape of prefabricated components can complicate transportation, leading to increased costs and potential delays. Oversized components required by the project must be carefully considered to avoid any delivery issues to the construction site (Hoínková, 2021). Another disadvantage is the need for accurate planning and coordination. Successful implementation of modular construction

requires meticulous planning and effective collaboration between all relevant parties to ensure compliance with transportation limitations and quality assurance standards. Lack of proper coordination may result in quality assurance issues (Akinradewo, et al., 2021). Additionally, there is lingering scepticism surrounding modular construction. Despite its capability to comply with regulatory standards, it is often viewed as inferior by professionals and financial institutions. This negative perception can make it challenging for homeowners to obtain mortgages for their modular homes, possibly due to territorial regulations or psychological factors (Hoínková, 2021).

2.8.11.3 Impact of Modular Construction on Affordable Housing Delivery

Modular construction has the potential to positively impact affordable housing delivery. Its unique characteristics and advantages make it an attractive option for affordable housing projects. One prime example of the impact of modular construction is its fast delivery process. Modular units are constructed off-site in a controlled factory environment, allowing for simultaneous on-site preparation. This parallel construction process significantly reduces construction time compared to traditional on-site methods (Thomson, 2019). The ability to complete modules in a factory setting while site preparation takes place expedites the overall project timeline, enabling faster delivery of affordable housing units. Another significant impact of modular construction is its quick assembly options. Modular units are designed to be easily transported and assembled on-site, minimising construction-related disruptions and disturbances in the surrounding area. The efficient assembly process reduces on-site labour requirements and the associated costs, leading to cost savings in the construction phase (Thomson, 2019). This cost-effectiveness contributes to the affordability of the housing units. Modular construction offers lower development costs compared to traditional construction methods. The controlled factory environment allows for efficient material usage, reduced waste, and optimized resource allocation (Thomson, 2019). The economies of scale achieved in the factory setting result in cost savings, making modular construction a cost-effective option for affordable housing projects. These lower development costs translate into more affordable housing options for prospective buyers or tenants. By reducing construction times and costs, modular construction can contribute to more efficient and affordable housing solutions.

2.8.12 3D Printing

3D printing, also known as additive manufacturing, is a technology that has the potential to revolutionise the construction industry. It involves the creation of physical objects by depositing materials layer by layer based on a digital model (Moghayedi, et al., 2024). In the context of construction, 3D printers use a specialised concrete mix that is pumped through a concrete nozzle controlled in three dimensions. This technology offers increased structural efficiency, reduced material consumption and waste, improved design-build efficiency, customisation possibilities, enhanced creativity and architectural freedom, minimal on-site health and safety issues, reduced construction time and costs, and decreased environmental impacts (Buchanan & Gardner, 2019; Moghayedi, et al., 2024).

2.8.12.1 Advantages of 3D Printing in Construction:

One major advantage of 3D printing in construction is the improved construction time and costs. The reduced set-up time for manufactured components and the faster build time for specific sections of a house lead to significant time savings compared to conventional construction methods (Leal, et al., 2017; Buswell, et al., 2007). This accelerated construction process results in lower project costs, as the financial loss associated with longer construction timelines is minimised (Buchanan & Gardner, 2019). Additionally, 3D printing allows for

increased automation, which can improve productivity by replacing certain on-site tasks typically performed by humans (Richardson, 2017).

2.8.12.2 Disadvantages of 3D Printing in Construction:

However, there are challenges that come with the adoption of 3D printing in construction. One such challenge is the social acceptability of automated systems replacing human labour. Concerns about job security and the perceived quality of products produced through automation hinder the widespread acceptance of 3D printing (Mahachi, 2021; Richardson, 2017). The novelty and uncertainty surrounding the technology contribute to preconceived notions and resistance to its adoption. Another challenge is the initial costs associated with adopting 3D printing technology. Early adoption leads to an "economic penalty" due to limited material supply and increased capital outlay (Buchanan & Gardner, 2019; Mahachi, 2021). The construction industry, being cost-sensitive, requires competitive pricing, which can be a barrier to the widespread adoption of 3D printing.

2.8.12.3 The Impact of 3D Printing on Affordable Housing Delivery:

3D printing technology has the potential to revolutionise affordable housing delivery by addressing key challenges in cost and time efficiency. By addressing key challenges in cost and time efficiency, it offers several prime examples of the impact on the affordable housing sector. One primary impact of 3D printing is its ability to significantly reduce construction time and costs. The automated nature of 3D printing allows for faster completion of housing projects compared to traditional construction methods (Buchanan & Gardner, 2019). The layer-by-layer printing process eliminates the need for extensive manual labour, resulting in shorter construction timelines. This accelerated construction process translates into cost savings, as labour costs are reduced, and material waste is minimised (Moghayedi, et al., 2024). The reduced construction time and cost efficiency contribute to improved affordability, making housing more accessible to individuals and families with limited financial resources. 3D printing technology enables efficient resource utilisation and waste reduction. The precise deposition of materials through 3D printing ensures minimal material waste, optimising material consumption during the construction process (Buchanan & Gardner, 2019). This resource efficiency further contributes to cost savings and affordability. The ability to use locally available materials or recycled materials in the 3D printing process can also reduce material transportation costs and environmental impact, enhancing sustainability in affordable housing projects. The customisation possibilities offered by 3D printing are another prime example of its impact on affordable housing delivery. This technology allows for the creation of tailored designs and structures, accommodating the specific needs and preferences of affordable housing projects (Buchanan & Gardner, 2019). Whether it's adapting to different climatic conditions, addressing specific community requirements, or considering the spatial needs of households, 3D printing offers design flexibility that can optimise the functionality and suitability of affordable housing units. Customisation enhances the liveability and comfort of the housing, providing occupants with homes that meet their unique needs. However, to fully harness the potential of 3D printing in affordable housing, addressing social acceptability and initial cost challenges is crucial. Educating beneficiaries and the wider public about the benefits and quality standards of 3D-printed housing units is essential for overcoming scepticism and fostering trust in this innovative construction method (Mahachi, 2021). By addressing these challenges, 3D printing can truly transform the affordable housing sector, offering efficient, affordable, and customised solutions to meet the growing demand for accessible housing.

2.8.1 Overview of the Innovative Technologies

The technologies presented in this section propose various advantages and disadvantages that have significant impacts on the affordable housing delivery and/or affordability. The impacts were best summarised in the Table 2.3.

2.8.1 Integrating Innovative Technologies for Affordable Housing Delivery

Integrating various innovative technologies can significantly enhance the delivery and affordability of affordable housing in South Africa. The combined use of technologies such as UAVs, BIM, GIS, smart sensors, IoT devices, modular construction, 3D printing, AI, PPM, VR, and AR can effectively address multiple challenges within the housing supply chain. UAVs provide real-time aerial data that, when integrated into BIM models, enhance site analysis and monitoring. GIS enhances spatial analysis, while smart sensors and IoT devices offer real-time updates on material usage and equipment performance. Modular construction and 3D printing enable faster and cost-effective building methods. AI and PPM tools optimize project planning and execution, while VR and AR improve design visualization and stakeholder engagement. This holistic approach maximizes the benefits of each technology, leading to improved project outcomes, reduced delays, cost savings, and enhanced quality control in affordable housing delivery.

Table 2.3 Overview of Innovative Technologies for Affordable Housing Delivery or Affordability

Technology	Advantage	Disadvantage	Impact on Affordable Housing Delivery or Affordability
OOP	Reusability of code, modular design	Complexity, resource intensity	Improved software development and organisation, potential for increased development costs
PPM	Efficient project planning and coordination	Lack of flexibility, complexity	Enhanced project management and coordination, potential for increased implementation costs
BIM	Improved collaboration, design visualisation	High initial costs, data management	Streamlined design process, improved project coordination, potential for cost savings
GIS	Spatial data analysis, informed decision-making	Data accuracy and integration, cost of implementation	Improved site selection, planning, and resource allocation for affordable housing projects
Smart Sensors	Real-time monitoring, data-driven insights	Cost of implementation, data security	Enhanced safety and efficiency in construction, potential for energy savings
VR	Immersive design visualisation	High initial costs, hardware requirements	Improved design review process, enhanced stakeholder engagement

AR	Overlay of virtual information on the real world	Limited field of view, reliance on devices	Enhanced on-site construction visualisation, improved accuracy, and efficiency
3D Laser Scanners	Accurate as-built documentation	High equipment costs, data processing	Improved quality control, streamlined as-built documentation
AI	Automation, data analysis, decision support	Lack of transparency, ethical considerations	Enhanced efficiency, optimised resource allocation, potential for job displacement
UAVs	Rapid data collection, site inspection	Regulatory restrictions, limited payload	Improved site monitoring, enhanced safety, potential for reduced construction time
Modular Construction	Faster construction, improved quality control	Transportation challenges, design constraints	Accelerated project timelines, potential for cost savings and standardised construction
3D Printing	Design freedom, reduced material waste	Limited scalability, high equipment costs	Faster construction, potential for cost savings, customisation possibilities

2.9 Summary of Chapter

The literature review brings attention to the urgent need for the South African affordable housing sector to address the growing backlog of affordable housing units. Failure to do so can result in detrimental consequences such as the proliferation of slums, increased poverty levels, and the spread of diseases. In this context, affordable housing is defined as housing that does not exceed 30% of occupants' income, emphasising its critical role in ensuring accessibility to suitable housing. With the backlog currently standing at 3.7 million units and increasing annually, innovative solutions are imperative to effectively tackle this pressing issue.

The review highlights the significance of adopting modern practices that overcome developmental defects and prevent compromises in the quality of living spaces and residents' well-being. By delving into the South African affordable housing supply chain, it becomes evident that several factors contribute to the sluggish nature of the construction industry, including extended construction periods, miscommunication and mismanagement among design teams, lack of coordination and collaboration, limited innovation, and rework resulting from collaboration errors and miscalculations. These challenges significantly impede the timely and cost-effective delivery of affordable housing projects. However, the literature emphasises that innovative technologies and practices hold the key to successful affordable housing delivery. Table 2.3 provides a concise overview of the advantages, disadvantages, and impacts of various technologies, such as Object-Oriented Programming (OOP), Portfolio Project Management (PPM), Building Information Modelling (BIM), Geographic Information System (GIS), Virtual Reality (VR), Artificial Intelligence (AI), Augmented Reality (AR), Smart Sensors, Unmanned Aerial Vehicles (UAVs), Modular Construction, and 3D Printing. These technologies offer promising benefits, including improved software development and organisation, enhanced project management and coordination, streamlined design processes, and faster construction. Nonetheless, the review acknowledges that challenges, such as high adoption costs, limited flexibility, and resistance to change, must be addressed to ensure the successful implementation of these technologies. By harnessing the potential of these

innovative solutions, the South African affordable housing sector can overcome communication, coordination, collaboration, and rework issues prevalent in the supply chain. The integration of these technologies facilitates efficient data sharing, enhanced stakeholder collaboration, reduced design errors, and improved quality control. Ultimately, the adoption of innovative technologies presents a significant opportunity to expedite the delivery and affordability of affordable housing and enhance living conditions for the population.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research methods used to obtain data for the aim and objectives presented in this study, focusing on ensuring the reliability and validity of the results. The chapter begins with a discussion on the different methodological options considered, highlighting the strengths and limitations of each in the context of housing and technology research. Following this, the chosen methodology for this study is detailed, which effectively integrates both qualitative and quantitative elements to enhance the depth and breadth of the analysis. This comprehensive approach is further substantiated through an analysis of various scholarly articles that support its relevance and efficacy. The chapter concludes with an overview of the data collection process and a rationale for selecting thematic analysis as the ideal method for data analysis.

3.2 Research Philosophy

Research philosophy is an important consideration for any research project, as it provides guidance for collecting and analysing data (Žukauskas, et al., 2018). After careful consideration, this study will adopt a pragmatic research philosophy, which seeks to combine elements of both positivism and interpretivism. Pragmatism is a flexible and adaptable approach that recognises the complexity of the social world and the limitations of any single research paradigm (Creswell, 2014). By adopting a pragmatic stance, this study has incorporated both quantitative and qualitative data collection methods, as well as considered the subjective interpretations of participants. Pragmatism emphasises the importance of using methods and theories that are most appropriate for the research question at hand, rather than being tied to a specific paradigm (Creswell, 2014). In this way, the pragmatic approach aligns well with the objectives of this study, which seeks to investigate the impacts of innovative technologies on the delivery process and affordability of South African affordable housing using a combination of quantitative and qualitative data.

3.3 Research Paradigm:

After reviewing the available research paradigms, it has been determined that the research methodology for this study will be grounded in a realistic research philosophy. While there are two predominant paradigms, positivism and interpretivism, the combination of quantitative and qualitative data collection and analysis methods necessitates the use of a philosophy that considers the subjective nature of humans. As Lancaster (2005) explains, a realistic research philosophy is a viable alternative that is based on the principles of both positivist and interpretivist research philosophies. This philosophy aligns with the goals of this study, which seeks to understand the impacts of innovative technologies on the delivery process and affordability of South African affordable housing. By adopting a realistic research philosophy stance, this study will be better equipped to understand the subjective experiences of the participants while also utilising objective data to draw meaningful conclusions.

3.4 Research Approach

The nature of this study requires a mixed-method approach for data collection and analysis. A mixed method is a research approach that combines both qualitative and quantitative methods during the data collection and analysis phases in the same study (Shorten & Smith, 2017). Malina, et al. (2011) state that combining these methods results in a stronger research outcome than either method does individually. When both approaches are combined, the potential

strengths of qualitative and quantitative methods can be harnessed, allowing researchers to explore diverse perspectives from the data collected. Pole (2007) argues that combining these methods can build on their strengths and minimise the limitations of either methodology when used alone.

3.4.1 Strengths and Weaknesses of Using a Mixed Method Approach:

Using a mixed-method approach will allow this study to uncover appropriate answers to the main research questions and objectives that neither quantitative nor qualitative methods could answer alone. Mixed method approaches are key in finding and understanding connections or contradictions between qualitative and quantitative data. This research approach will enhance the validity of the data collected and will give key participants the space to express their viewpoints and experiences in detail (Shorten & Smith, 2017). The combination of both methods allows researchers to build stronger studies, leading to increased inferences (Pole, 2007). Although useful, mixed methods within one study can increase the complexity of the research, requiring more resources (in this case, time). It can also lengthen the duration of the research by affecting sample selection, data collection, and data analysis (Shorten & Smith, 2017). For example, in accordance with qualitative research, the sample size is often small and carefully chosen to meet the study's needs. On the contrary, for quantitative research, the sample size is larger (Pole, 2007). With a mixed-method approach, both these samples are combined, increasing the overall data needed for collection.

3.4.2 Types of Mixed Methods:

Although there are various mixed-method approaches, including explanatory, exploratory, parallel, and nested (embedded) designs, this study will use a parallel mixed method to collect data (Shorten & Smith, 2017). A parallel mixed method approach combines the analysis and collection of data concurrently. This method contrasts with the explanatory or exploratory mixed methods, in which quantitative data is collected and analysed first. In explanatory mixed methods, the qualitative data is collected and analysed afterwards to justify the quantitative data. The same principle is applied in exploratory mixed methods, but the qualitative data is collected and analysed first, and the quantitative data is collected and used to examine the findings empirically (Shorten & Smith, 2017).

3.4.3 Justification of Parallel Mixed Method Approach:

A parallel mixed method approach is recommended for this study as it provides robustness to the data collected by combining both qualitative and quantitative research approaches (Malina, et al., 2011). According to Malina et al. (2011), this approach creates space for new lines of thinking, highlights any anomalies or paradoxes, and provides new insights into the research topic. By using both methods, this study aims to confirm assumptions of the usage of innovative technology in South Africa, ideally theory-testing, using a quantitative research method, given the need for a large sample size to understand its potential applications. On the other hand, a qualitative research approach is appropriate when the aim is to describe or find meaning (Pole, 2007). It would be advantageous to use a qualitative research approach to understand why professionals use innovative technologies and their perceived importance, relevance, and necessity in their everyday practice. Combining these two approaches provides a deeper understanding of the scope and deeper issues of innovative technology adoption. Thus, the study will use a parallel mixed-method approach to achieve its research objectives.

3.5 Target Population

3.5.1 Qualitative Population:

The determination of a well-defined target population is integral to the objectives of this study. This definition encompasses the characteristics of the population elements, the sampling units that encompass these elements, and the geographical scope in which these population elements are located. In the case of the qualitative data collected, the target population is specified as "experts/professionals, policymakers, and academics who have direct involvement or prior experience in affordable housing development within South Africa as part of their professional background." By establishing a clear target population, it becomes feasible to identify the appropriate criteria for inclusion and exclusion, as presented in Table 3.1, which align with the research objectives.

Table 3.1 Inclusionary and Exclusionary Criteria of The Qualitative Population

Inclusionary	Exclusionary
Experts/Professionals, Policymakers and academics involved in affordable housing development	Experts/Professionals, Policymakers and academics that aren't involved in affordable housing development
Affordable Housing	Retail, Industrial and Commercial Buildings
Affordable Housing Development	Retail, Industrial and Commercial Building Development
Professionals must live or have extensive experience developing affordable housing in South Africa	Professionals live outside or don't have prior experience developing affordable housing in South Africa

3.5.2 Quantitative Population:

The target population for the quantitative data collected is defined as *"representatives of companies involved in the development process of affordable housing projects within South Africa."* Similar to the qualitative population, the inclusionary and exclusionary information for the defined target population is presented in Table 3.2.

Table 3.2 Inclusionary and Exclusionary Criteria of The Quantitative Population

Inclusionary	Exclusionary
Home developers involved in affordable housing development projects	Developers involved in construction projects outside of affordable housing developments
Affordable Housing	Retail, Industrial and Commercial Buildings
Affordable Housing Development	Retail, Industrial and Commercial Building Development
Professionals must live or have extensive experience developing affordable housing in South Africa	Professionals live outside or don't have prior experience developing affordable housing in South Africa

3.6 Sampling Technique and Sample Size

The sample size for this study is based on the scope of time, resources, and personnel available to conduct the study. As mentioned, this study will use both qualitative and quantitative methods to conduct the research. For the qualitative data, one-on-one interviews will be conducted with relevant experts, academics, and policymakers within the affordable housing

sector. For the quantitative data, online surveys will be sent to various professionals, academics, or policymakers to collect a larger set of results. In order to determine the desired sample size, the following variables were deduced to calculate the sample size, these variables include the population size, error of margin, standard confidence level and the population portion level. It was decided that the sample population of the population would consist of 5000 home development representatives, this value is based on a spreadsheet database of home developers registered with the National Home Builders Registration Council (NHBRC) which had a total number of 5000 developers, authors such as Joseph & Bélisle (2013) highlight scenarios where large sample populations ranging from 5000 to 100,000 are necessary to accurately estimate the effects under varying conditions of misclassifications and uncertainty. Given the mixed-methods nature of this study, a stratified random sampling technique will be employed to ensure a representative sample of the diverse roles within the affordable housing sector (Shabbir & Gupta, 2010). This technique will divide the total sample population of 5,000 registered home developers into strata based on their roles (e.g., architects, project managers, policymakers). Within each stratum, individuals will be randomly selected to participate in the study, ensuring that each subgroup is proportionately represented. This method enhances the reliability and validity of the results by reducing sampling bias and providing a comprehensive overview of the sector. For qualitative data, purposive sampling will be used to select key informants who are experts in affordable housing. This targeted approach allows for in-depth exploration of specialised knowledge and insights into the sector's challenges and opportunities. By integrating these sampling techniques, the study aims to balance depth with breadth, capturing both quantitative trends and qualitative insights across the sector.

This study would require an error margin of ± 5, a standard confidence level of 95%, and a population proportion of 50%. Using these variables, the sample frame was calculated to be 385. Based on limitations such as the project timeline, limited responses from prospective interviewees, and the poor quality of some survey responses, only a total sample size of 100 was used for this study despite the calculated final sample frame value of 385. A final sample size of 100, although less than the desired 385, can still be used and justified. An article by Bujang & Baharum (2017) titled "A Simplified Guide to Determining Sample Size Requirements for Estimating the Value of Intraclass Correlation Coefficient: A Review" offers valuable insights that are applicable to sample size considerations in research. Bujang & Baharum (2017) further emphasizes the importance of precision in sample size determination and highlight that smaller sample sizes can still yield valid and reliable results, particularly when resources and constraints limit the feasibility of larger sample sizes. By clearly identifying the trade-off between precision and practicality, this article further supports the notion that a sample size of 100 can be justifiable in research studies where practical considerations, such as limited resources or time constraints, necessitate a smaller sample size. Furthermore, the author's research re-iterates finding the balance between statistical rigour and real-world constraints when determining sample size requirements.

3.7 Unit of Analysis

The unit of analysis is a fundamental component of a study. Its purpose is to identify what the research study aims to study (Yin, 2013). It derives subject matter from the main research question of this study, which is: "What are the impacts of innovative technologies on the delivery process and affordability of South African affordable housing?" The focused subject matter would be "innovative technology within South African Affordable Housing Development." Once the subject matter has been understood, the unit of analysis will be determined as the analysis of data based on the opinions of experts, academics, and policymakers involved in the interview process. Considering this, each home developer's demographic characteristics, opinions, and experiences are being analysed to draw conclusions

about the impact of innovative technologies on the delivery process and affordability of affordable housing in South Africa.

3.8 Method of Data Collection

This section provides a detailed justification for the data collection methods employed during this research.

3.8.1 Qualitative Data

The qualitative data for this research was obtained through online interviews using Zoom and Microsoft Teams as the video calling method. These interviews were conducted with respondents who are experts, academics, or policymakers within the affordable housing sector. The goal of these interviews is to gain a deeper understanding of the relevance and importance of innovative technology in the real application of affordable housing development. This information is used to complement or elaborate on the online surveys collected. The articulated questions aimed to understand whether these participants see the need for a change in the delivery of affordable housing, whether they believe technology is a viable solution, and if they think it will be best applied in South Africa. Hence, the questions cover three categories:

- *Identifying and explaining the current challenges faced by the affordable housing sector.*
- *Determining whether innovative technology can be a possible solution for challenges or barriers to affordable housing development, highlighting the strengths and weaknesses of various technologies.*
- *Sharing their professional opinion on whether such technologies will benefit the South African affordable housing delivery and costs.*

Once these three categories were articulated, 10 interview questions and the interview protocol were devised and can be viewed in Appendix A and B. These questions created space for the participants to share their professional opinions based on their experience in this sector. Once the questions were approved and received ethics clearance, the interview process could commence. Each interview was conducted online through Zoom or MS Teams, and the interviewee granted the interviewer permission to record the conversation for later transcription. Once completed, the recordings were saved on OneDrive for secure online storage. A randomly selected interview transcript can be found in Appendix C.

To mitigate potential selection biases, verbatim transcripts of the interviews were analysed, ensuring that the interpretation remained faithful to the participants' original responses. Every effort was made to formulate non-leading questions to avoid influencing the participants' answers and maintain objectivity.

3.8.2 Quantitative Data

An online survey was created to collect quantitative data. Google Forms were used to draft the survey, with the intention of creating an easier process for participants to fill it in using any available device. The goal of the survey is to get a broader understanding of innovative technology in the affordable housing sector. The survey was opened to home development companies, specifically representatives within the company; the experience of the respondent may vary, from relatively new employees to professionals in this sector with many years of experience. The purpose is to get a wider consensus on the relevance of innovative technology among the working class in this sector. The online survey was split into the following categories:

- **General Information** – the aim of this section is to get a deeper understanding of the participant's professional history and experience within the affordable housing sector.
- **Technical Section** – this section determines whether the participant believes there is a need for the housing sector to change the rate at which affordable housing is delivered and whether they can identify the challenges or barriers that may inhibit the delay in delivery and high costs of affordable housing.
- **Innovative Technologies** – This section aims to understand the participant's view of innovative technologies; to see if they believe they will be useful in the affordable housing sector and if they can identify the challenges/barriers to adopting these technologies in the South African housing sector. Participants were asked specifically about technologies such as BIM, GIS, Project Portfolio Management, Object Oriented Programming, Drones, 3D Laser Scanners, 3D Printers and Modular Construction. However, the literature examines these technologies and more to gain a more robust understanding of innovation in construction, while the technologies given to the respondents were practically being used in the current market in South Africa.

From these three categories, 19 questions and the online survey was devised and can be viewed in Appendix D and E. Participants were contacted via email or text message or through online forums/groups to participate in the online survey. Then, a Google Forms link was sent to them, and they could fill in the survey on whatever device they were using to view the link. A total of 100 surveys were filled in and submitted, and users-maintained anonymity throughout. Each survey is stored safely on Google Forms online, avoiding any risk of loss or corruption. The questionnaire surveys can be viewed in the appendix.

3.9 Method of Data Analysis

In accordance with this study's data collection approach, which includes both qualitative and quantitative data, thematic analysis and descriptive and inferential statistical approach is adopted for data analysis. This section examines the approach with justification for its implementation.

3.9.1 Qualitative Data

3.9.1.1 Thematic Analysis

Thematic analysis proves to be a valuable approach for examining qualitative data, including the interviews conducted with experts, policymakers, and academics in this study. This method entails the identification, analysis, and interpretation of patterns that emerge from the data. The process adheres to five key principles: close observation, theme identification, analysis, systematic examination of individual cases, and quantification of qualitative data. In this thematic analysis, the main source of data will be the transcripts from the qualitative interviews, providing rich insights for analysis.

3.9.1.2 Process of Analysis

The process of thematic analysis consists of three phases:

- (1) Reduction of text,
- (2) Exploration of text,
- (3) And integration of text (Attride-Striling, 2001).

Figure 3.1 outlines the steps used in this study to conduct the data analysis process for the thematic analysis of the qualitative interview transcripts.

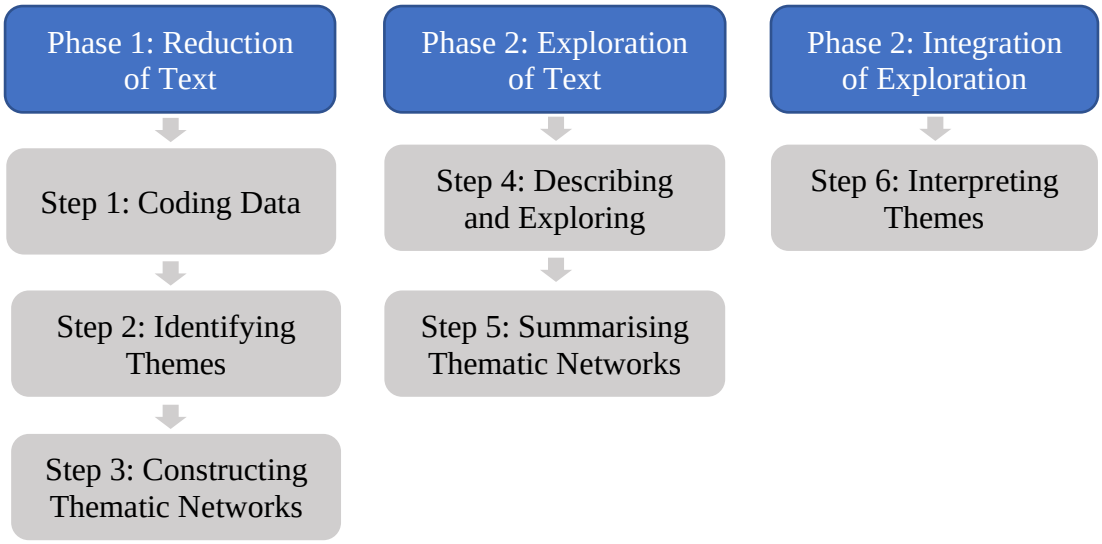


Figure 3.1 The Process of Thematic Analysis (Attride-Striling, 2001)

3.9.1.3 Credibility and Dependability of Qualitative Data:

When analysing the qualitative data, a non-biased approach was adopted to ensure that all interpretation and collection of data was performed in a way that does not favour a particular outcome but rather provides an objective viewpoint from the qualitative interviewees. However, it is essential to acknowledge the potential for interviewer bias, where the interviewer's own beliefs and expectations might unconsciously influence the responses of participants. Additionally, cognitive biases, such as confirmation bias, where the interviewer might give more weight to responses that align with their preconceptions, were carefully monitored and mitigated by adhering to a structured interview guide and maintaining reflexivity throughout the research process. Each question developed for the interview was based on the predetermined objectives of this study. However, when ensuring the credibility and dependability of the qualitative data in this study, two key components were considered, as prescribed by William (2022) to ensure the effective credibility and dependability of quantitative data. These components consist of:

- (1) Ensuring credibility, this study ensured that the results of the qualitative data seemed believable or credible from the perspective of the participants in the qualitative interview process. This study looked further into various credibility methods to ensure the credibility of the research. These methods were proposed by Statistic Solutions (2022) who stated that triangulation, using various methods, data sources, observers, or theories to understand the data captured, is an appropriate tool used for the credibility of qualitative data. These include:
    - Methods triangulation – Utilising various data collection methods to ensure consistency in findings.
    - Triangulation of Sources – Using multiple sources of data within the same method, such as interviewing people at different times or comparing interviewees with different perspectives (experts, academics, and policymakers).
    - Analyst Triangulation – Reviewing findings with multiple analysis methods.
    - Theoretical Triangulation – Analysing data through multiple theoretical perspectives.

- (2) Due to the ever-changing nature of the world, this study took into consideration this factor when processing the data to ensure the dependability of the data collected. Various changes in settings can affect how research is approached, hence the adaption to these changes.

3.9.2 Quantitative Data:

3.9.2.1 Testing the Normality of the Data

The Shapiro-Wilk test was conducted to assess the normality assumption of the survey data, the calculated values from SPSS can be viewed in Appendix F. The test was conducted on all the questions excluding the demographic information of the participants (the technical assessment and assessment of innovative technology were tested) this method is used with all the inferential tests. The results of the test indicated that the survey responses had a significance value of less than 0.001, as seen in the Appendix. According to the literature, when a produced value is less than 0.05, the data significantly deviates from a normal distribution, hence concluding that the survey responses are not normally distributed (Aerd Statistics, 2018). This finding suggests that non-parametric statistical tests would be more appropriate for analysing the data, and the results of these tests will be presented in the following section. Furthermore, the results of the Shapiro-Wilk test will also be used as a reference point when interpreting the findings of the non-parametric tests.

3.9.2.2 Testing for reliability and consistency

After conducting the Shapiro-Wilk test to assess the normality of the survey data and with further tests using the Kruskal-Wallis test to determine whether there are statistically significant differences between the different groups of respondents and their ratings of the housing project features, there was a need to turn to the reliability of the survey instrument. One commonly used measure of internal consistency is Cronbach's alpha, which provides information on the extent to which the survey items are interrelated and measures the same underlying construct (UCLA, 2023). In the current study, the Cronbach alpha analysis is conducted to evaluate the reliability of the survey instrument used to collect data on the attitudes and preferences of the participants towards the affordable housing project. This analysis is crucial for ensuring that the survey instrument is a valid and consistent tool for measuring the participants' opinions and attitudes towards the housing project. The results of the Cronbach Alpha test provide valuable insights into the quality of the data collected through the survey and can help to inform decisions about the interpretation and use of the results. The results of the Cronbach Alpha can be seen in Table 3.3.

Table 3.3 Cronbach Alpha Analysis Results for the Quantitative Survey Data.

Sub-Section	Survey Questions	Cronbach Alpha Results
Home Developer's Familiarity with Innovative Technologies	Please indicate the level of familiarity with the following technologies.	*0.866*
	Please indicate the level of use of the following innovative technologies in the design and construction of houses in these projects.	*0.902*
	Please indicate the challenges and barriers to adopting the following innovative technologies in designing and constructing affordable housing projects (Please, select all that apply).	*0.838*

	What are the impacts of adopting the following technologies on the delivery of South African affordable housing?	*0.950*
	What are the impacts of adopting the following technologies on the costs of South African affordable housing?	*0.951*
	Overall Calculated Cronbach Alpha Results	***0.657***

According to Nunnally & Bernstein (1994) in their book "Psychometric Theory," the Cronbach's alpha coefficient serves as an important measure of internal consistency reliability. In the context of the results displayed in Table 3.3, a Cronbach's alpha coefficient of 0.657 suggests that the collected data demonstrates an acceptable level of reliability. Nunnally & Bernstein (1994) explain that the interpretation of Cronbach's alpha coefficients involves assessing the extent to which items in a scale or instrument are consistently measuring the same underlying construct. Generally, a higher alpha coefficient indicates greater internal consistency among the items, implying that the data is more reliable. While there is no universally agreed-upon threshold for an acceptable alpha coefficient, values above 0.6 or 0.7 are often considered satisfactory. However, various scholars seem to indicate a value above 0.9 may result in the indication of redundancy in the data collected or survey questions, hence the growing misconception that an extremely high Cronbach alpha is an indication of internal consistency (Cho & Kim, 2015). Nevertheless, by obtaining a Cronbach's alpha coefficient of 0.657, the data demonstrates a moderate-to-good level of internal consistency, supporting the reliability of the measurements. This finding aligns with Nunnally and Bernstein's guidance on interpreting Cronbach's alpha coefficients, indicating that the data collected can be considered reliable for further analysis and interpretation (Nunnally & Bernstein, 1994).

3.9.2.3 Inferential Statistics Analysis:

Inferential statistics is a branch of statistics that involves using statistical methods to draw conclusions about a population based on data from a sample of that population. One commonly used method in inferential statistics is the Relative Importance Index (RII). The Relative Importance Index (RII) is a widely recognised statistical measure in social science research and survey data analysis. It assesses the relative importance of different factors or variables in relation to a particular outcome or response variable by providing a weighted average of responses to a set of Likert-scale questions or items, where the weights reflect the importance of each item in explaining the variation in the outcome variable. The RII ranges from 0 to 1, with higher values indicating greater relative importance. It is a crucial tool for policymakers and researchers to prioritise interventions and allocate resources accordingly. This study utilised the RII to identify the key factors affecting the delivery process and affordability of South African affordable housing, particularly with regard to the impact of innovative technologies. It is important to note that the RII has some limitations and assumptions that must be considered. One limitation is that it assumes each item is equally important in explaining the outcome variable, which may not always hold true. Additionally, the RII assumes that the weights assigned to each item are independent of the level of the response to the item, which may not be accurate in all cases. To address these limitations, this study employed a rigorous survey design and data analysis process that included expert opinion to assign weights to survey items and statistical tests to assess the validity of RII results. Despite these limitations and assumptions, the RII remains a valuable statistical measure for identifying the key factors that affect the delivery process and affordability of affordable housing.

In the context of this study, weights were assigned to the factors using a Likert scale that ranged from 1 to 5, with 1 representing "Strongly Disagree" and 5 representing "Strongly Agree." The weights were expressed as a percentage or proportion of the total weight assigned to all factors. For example, for the survey question "To what extent do you agree with the following statement: Delays in the development of South African affordable housing are a recurring event?", the researchers assigned weights as follows: Strongly Disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, and Strongly Agree = 5. The question had a total weight of 100, and the sum of the weights was 348. Utilising the formula for RII, an RII value of 0.696 was calculated for this question, indicating that home developers perceived delays in the development of South African affordable housing as a significant challenge. The formula used to calculate the RII is as follows:

$$RII = (1/N) * \Sigma (wi * xi) / \Sigma(wi) \qquad Eq\ 3.1$$

Where:

- N is the total number of factors being considered
- wi is the weight assigned to the i-th factor (usually expressed as a percentage or proportion)
- xi is the mean score for the i-th factor (usually on a scale of 1 to 5)

The values of RII fall between 0 and 1, where a higher value indicates a stronger association or influence of the factor on the outcome of interest.

3.9.2.4 Hypothesis Testing

The hypothesis testing section of this study focuses on using the Kruskal-Wallis test to examine the impact of innovative technology utilisation on affordable housing projects. The aim is to test two hypotheses related to the relationship between technology usage and affordability, as well as the perceived efficiency of the delivery process. The Kruskal-Wallis test will be conducted to determine whether there is a significant relationship between the level of technology utilisation and the perceived efficiency of the delivery process. This test will assess both positive and negative associations, providing a comprehensive analysis of the data. The results of the Kruskal-Wallis test will be used to determine if there is a significant relationship between the variables. No linear regression analysis or equation was utilised in this particular study. The focus will solely be on examining the findings from the Kruskal-Wallis test to gain insights into the impact of technology utilisation on the efficiency of affordable housing projects.

This study's hypotheses:
Hypothesis 1:
The utilisation of innovative technologies in affordable housing design and construction has a significant impact on the affordable housing delivery process.

- Null Hypothesis (H0): There is no significant impact of the utilisation of innovative technologies on the perceived efficiency of the delivery process in affordable housing projects.
- Alternative Hypothesis (H1): There is a significant impact of the utilisation of innovative technologies on the perceived efficiency of the delivery process in affordable housing.

Hypothesis 2:

The level of usage of innovative technologies has a significant impact on the affordability of affordable housing projects.

- H0: There is no significant impact of the level of usage of innovative technologies on the affordability of affordable housing projects.
- H1: There is a significant impact of the level of usage of innovative technologies on the affordability of affordable housing projects.

Table 3.4 Survey Questions Used in The Hypothesis Test

Section	Survey Question
Home Developer's Familiarity with Innovative Technologies	Q. 16 Please indicate the level of use of the following innovative technologies in the design and construction of houses in these projects.
	Q. 19 What are the impacts of adopting the following technologies on the delivery of South African affordable housing?
	Q. 20 What are the impacts of adopting the following technologies on the costs of South African affordable housing?

Table 3.5 Kruskal-Wallis Hypothesis Test Summary:

Technology	Survey Question Combination		Sig (p-Value)	Decision
	Question	Question		
Section A				
BIM	Q.16	Q.19	*0.099*	*Retain the null hypothesis*
GIS	Q.16	Q.19	*0.466*	*Retain the null hypothesis*
Smart Sensors	Q.16	Q.19	***0.009***	*Reject the null hypothesis*
3D Laser Scanners	Q.16	Q.19	*0.700*	*Retain the null hypothesis*
Drones	Q.16	Q.19	*0.116*	*Retain the null hypothesis*
Modular Construction	Q.16	Q.19	*0.337*	*Retain the null hypothesis*
3D Printers	Q.16	Q.19	*0.609*	*Retain the null hypothesis*
OOP	Q.16	Q.19	*0.394*	*Retain the null hypothesis*
PPM	Q.16	Q.19	*0.644*	*Retain the null hypothesis*
Section B				
BIM	Q.16	Q.20	*0.074*	*Retain the null hypothesis*
GIS	Q.16	Q.20	*0.113*	*Retain the null hypothesis*
Smart Sensors	Q.16	Q.20	*0.295*	*Retain the null hypothesis*
3D Laser Scanners	Q.16	Q.20	*0.358*	*Retain the null hypothesis*
Drones	Q.16	Q.20	*0.531*	*Retain the null hypothesis*
Modular Construction	Q.16	Q.20	***0.009***	*Reject the null hypothesis*
3D Printers	Q.16	Q.20	*0.551*	*Retain the null hypothesis*
OOP	Q.16	Q.20	***0.049***	*Reject the null hypothesis*
PPM	Q.16	Q.20	*0.318*	*Retain the null hypothesis*

Upon conducting a comprehensive analysis of the results presented in Table 3.5 for both Section A and Section B, valuable insights into the relationship between the utilisation of innovative technologies and the delivery rate, as well as the perceived affordability of affordable housing, have emerged. In Section A, which delves into the relationship between technology utilisation and the delivery rate of affordable housing, the statistical tests indicate that the majority of the technologies, including BIM, GIS, 3D Laser Scanners, Drones, Modular Construction, 3D Printers, OOP and PPM, do not exhibit a significant impact on the delivery

rate. The p-values associated with these technologies are higher than the predetermined significance level, leading to the retention of the null hypothesis. This implies that the level of utilisation of these technologies does not have a substantial influence on the delivery rate of affordable housing. However, in the case of Smart Sensors, the p-value is below the predetermined significance level, indicating a statistically significant relationship. This suggests that the level of utilisation of Smart Sensors has a significant impact on the delivery rate of affordable housing. Further analysis and exploration of this technology are warranted to understand the specific benefits and implications it offers for enhancing the delivery rate of affordable housing. Shifting the focus to Section B, which investigates the relationship between technology utilisation and the perceived affordability of affordable housing, the statistical tests reveal that out of all the technologies, Modular Construction, OOP, and PPM exhibit statistically significant relationships with the delivery rate of affordable housing as indicated by p-values below the significance level. The rejection of the null hypothesis for these technologies signifies their potential to exert a notable impact on the delivery rate. The meticulous analysis of both Section A and Section B underscores that, in this study, the level of utilisation of most innovative technologies does not significantly impact the delivery rate and perceived affordability of affordable housing. The results of the analysis also draw attention to the significant impact of Smart Sensors on the delivery rate of affordable housing, as well as the influence of Modular Construction, OOP, and PPM on the affordability of such projects.

3.9.2.5 Analysis of the Kruskal-Wallis Test Results for Hypotheses on Innovative Technologies in Affordable Housing Design and Construction

Hypothesis 1:

The results of the Kruskal-Wallis test provide insights into the relationship between the level of utilisation of innovative technologies in affordable housing design and construction and the perceived efficiency of the delivery process. The null hypothesis (H0) states that there is no significant impact of the level of utilisation of innovative technologies on the perceived efficiency of the delivery process in affordable housing design and construction. On the other hand, the alternative hypothesis (H1) suggests that there is a significant impact. The analysis of Section A in the Kruskal-Wallis test reveals that the majority of the technologies, including BIM, GIS, 3D Laser Scanners, Drones, Modular Construction, 3D Printers, OOP, and PPM, do not exhibit a statistically significant impact on the delivery rate. This supports the retention of the null hypothesis (H0) and indicates that the level of utilisation of these technologies does not significantly influence the perceived efficiency of the delivery process in affordable housing. However, the statistically significant relationship found with Smart Sensors rejects the null hypothesis and suggests that the level of utilisation of Smart Sensors has a significant impact on the delivery rate of affordable housing. Further investigation is warranted to explore the specific benefits and implications offered by Smart Sensors in enhancing the efficiency of the delivery process.

Hypothesis 2:

The Kruskal-Wallis test also provides insights into the relationship between the level of usage of innovative technologies and the affordability of affordable housing projects. The null hypothesis (H0) posits that there is no significant impact of the level of usage of innovative technologies on the affordability of affordable housing projects, while the alternative hypothesis (H1) proposes that there is a significant impact. The analysis of Section B in the Kruskal-Wallis test reveals that Modular Construction, OOP, and PPM exhibit statistically significant relationships with the delivery rate. This leads to the rejection of the null hypothesis (H0) and supports the alternative hypothesis (H1), suggesting that the level of usage of these

technologies has a notable impact on the affordability of affordable housing projects. These findings emphasise the potential of Modular Construction, OOP, and PPM to contribute to enhancing the affordability of affordable housing.

Ultimately the results of the Kruskal-Wallis test align with the research hypotheses. While the majority of the innovative technologies do not significantly impact the perceived efficiency of the delivery process or affordability of affordable housing projects, Smart Sensors, Modular Construction, OOP, and PPM emerge as technologies that can potentially drive improvements in these areas. These findings highlight the importance of considering the specific impacts of different technologies in the context of affordable housing design and construction.

3.10 Ethics Consideration

As a general practice, the maintenance of ethical considerations should remain prominent within a research project. A set of ethical principles must be set to ensure that the collection, analysis, and storage of data are done ethically. Before committing to collecting qualitative data, a consent form should be generated. Consent forms ensure that participants fully understand the nature of the research, their rights as participants, and the ways in which their data will be used, and to obtain their explicit and voluntary consent to participate in the study. The consent form included information that the participants are volunteering to take part in the study and are not subject to any form of coercion or unnecessary pressure to participate. The form also clearly states that participants are not required to pay any financial obligations in exchange for their participation. Another ethical consideration included in the form is consent from the participants to record the interview. It is important to ensure that participants are aware that the interview is being recorded and have given their consent for any audio recordings to take place. In addition, the consent form is transparent with participants about how the data will be used. In this case, the form indicates that the data will be used for a master's project and may also be published in journals or presented at conferences. Finally, the consent form should state that the anonymity and confidentiality of the participant's information will be protected. However, it is imperative to prioritise ethical considerations in any research endeavour. Establishing a framework of ethical principles is crucial to ensure that data collection, analysis, and storage are conducted in an ethically sound manner. Therefore, the following ethical principles are applicable to both the qualitative and quantitative data gathered: obtaining informed consent, maintaining confidentiality, and providing a clear explanation of the implications and requirements for participation in the research. This paper made use of ethical consideration by initially receiving ethics clearance from the EBE Ethics by the Research Committee and the signed approval is in Appendix G.

3.10.1 Informed Consent and Confidentiality

Various scholarly articles, including research obtained through Field-Springer (2017), note that informed consent is obtained through a legally binding document stating the terms of participating in a research study. Such a form is a prerequisite to beginning the interview process for data collection. Therefore, the importance of this study is to integrate these documents within the qualitative interviews and quantitative online surveys.

3.10.1.1 Obtaining Informed Consent

The consent forms were prepared in two different forms. For the qualitative interviews, a separate form was sent out to the interviewee before the interview process. The form ensured the interviewee was aware of the voluntary nature of the interview, the detailed purpose, the disclosure of information, and the terms of participation. No interviews would be conducted before the acceptance of the informed consent. This process was similar to the quantitative

online surveys; however, the consent form was built into the Google Forms link. The interviewee could only commence with the survey once they had accepted and read through the terms of the consent section. The form would only be accepted by Google if the consent form had been read.

3.10.1.2 Maintaining Confidentiality:

It was a priority to ensure that the data collected and any sensitive information, such as names, emails, or phone numbers that were received, remained confidential after the interviews or after the acceptance of the online surveys. The interviewees were informed of their confidentiality within the consent forms for both the qualitative and quantitative data collected. In terms of the recorded interviews, an encryption system was put in place to ensure confidentiality in the saved files.

3.10.2 Consequences of Participation

The interviewees were explicitly informed about the voluntary nature of their participation in the interview process for this study. They were assured that they had the freedom to withdraw from the study at any point during its duration. The purpose of this communication was to ensure that the interviewees were fully aware of their rights and the optional nature of their involvement in the interview process, particularly considering the possibility of discussing personal or confidential information.

3.11 Summary of the Chapter

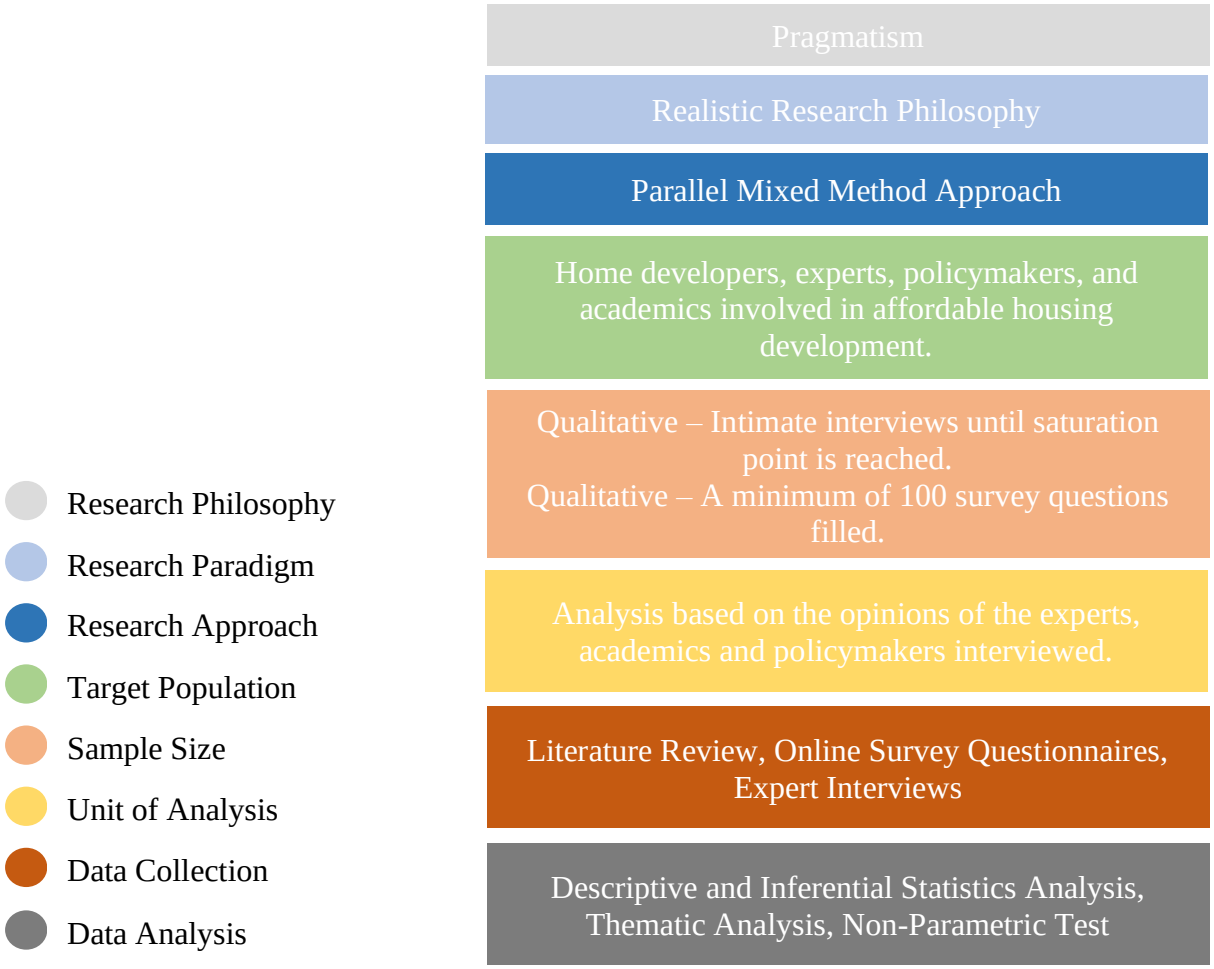


Figure 3.2 Summary of research methodology

The objective of this chapter was to identify the most suitable methodological approaches for this study. Both quantitative and qualitative research methods were used as the overarching research methods for this mixed method approach, as it best represents the data collection for this case study. These methods were justified using various scholarly articles as a basis for validity. The unit of analysis was then identified, which helps narrow the targeted population while determining both the inclusionary and exclusionary data used to determine the sample population. The unit of analysis in this case was determined as the use of expert knowledge as a basis for analysis on the subject matter of this study. The decision to use semi-structured interviews as a form of qualitative data collection and online surveys as a form of quantitative data collection was then made and justified. Once the data collection methods were understood, the data analysis methods were presented. The data analysis included both a thematic and inferential statistics analysis approach, based on the adoption of a mixed method approach as the overarching research method. Efforts were made to validate the survey instruments used in this study through pilot testing, which involved a small subset of participants representative of the larger sample. This process helped refine the questions for clarity and relevance, ensuring the reliability and validity of the data collected. This chapter concluded with the identification of all ethical considerations, including the methods by which respondents' confidential/personal information was kept safe and the mandatory nature of ethical consent. In addition to the limitations of the RII analysis, this study faced several other limitations. The mixed-method research design, while providing a comprehensive view, may introduce complexity in integrating qualitative and quantitative data. The reliance on self-reported data from surveys and interviews can lead to potential biases or inaccuracies. Additionally, the use of the Kruskal-Wallis test alone may not capture all nuances in the data, suggesting a need for complementary statistical methods to strengthen the analysis. A graphical summary of this study's research methodology is presented in Figure 3.2.

CHAPTER 4: DATA PRESENTATION AND ANALYSIS OF STUDY FINDINGS

4.1 Introduction

This section presents the results of a rigorous investigation into innovative technologies used in the affordable housing sector in South Africa. The data were collected from surveys and interviews, providing a comprehensive overview of the current state of the industry. The analysis examines key themes, including lifecycle costs and the potential for innovative technologies to improve efficiency. Findings are presented in four sections, offering unique perspectives on the data: first, the quantitative analysis, focusing on the descriptive and inferential statistical analysis, followed by the qualitative analysis which used a thematic method of analysis, then concluding with the discussion of findings. These sections provide a comprehensive and valuable contribution to affordable housing research in South Africa.

4.2 Analysing the Quantitative Data:

The quantitative analysis uses the descriptive statistical analysis method to further examine the data.

4.2.1 Analysis of Respondents' Information: Findings and Insights

The following descriptive statistical analysis section presents the results of a comprehensive investigation into the impact innovative technology has on home developers within South Africa. Through this analysis, descriptive statistics were used to summarise the data. Frequencies and percentages were calculated for each variable and for the measure of the perceived impact of innovative technologies on affordable housing. Graphical methods, such as histograms and pie charts, were used to visualise the data. For some results, the Relative Importance Index (RII) was used to summarise the data collected. This section lays the foundation for the subsequent analyses by providing a clear and concise overview of the data, setting the stage for inferential statistical analysis and thematic analysis to follow. The descriptive statistical analysis section is a critical component of this research, providing a robust and rigorous approach to data analysis and interpretation.

In terms of the data collected, a sample of 100 home development companies was recruited from the general population, with representatives from each company that were surveyed. The surveyed representatives had to have a minimum of a high school education and had to fall within the following categories within the field of the respondent: Engineer, Architect, Construction Manager, Quantity Surveyor and Contractors. Ultimately, participants have been involved in housing development. Data was collected using an online self-administered online survey, which included questions on demographic information (i.e., Designation of Respondent, Field of Respondent, Experience in Affordable Housing, how many affordable houses were delivered in the past 5 years, etc.) and Likert scale questions on the perceived impact of innovative technologies on the delivery and affordability of affordable housing in South Africa. The online survey was split into three sections to gain a detailed understanding of the participant's views on the topics within the subsections: Demographic Information, the Technical Expertise of the Representatives, and the Representative's Familiarity with Innovative Technologies Within Construction.

4.2.1.1 Background of Home Developers:

The educational background of the representatives in the study provides insight into their level of experience and expertise in the field, which in turn may impact their use of technology. With 64% of the participants having a postgraduate degree, it can be assumed that a significant

portion of the sample has a higher level of educational attainment and, therefore, a higher level of experience and knowledge in the field. This may explain why most participants have a higher level of use of technology. Moreover, the distribution of education levels among the participants highlights the importance of considering participants' educational backgrounds when conducting research. The distribution of education levels in the sample, as shown in Figure 4.1, can be used as a benchmark for future studies on technology use in similar fields. Additionally, it is also worth considering the impact of job positions on technology use. For example, representatives who hold higher-level positions may have access to and use more advanced technologies than those in entry-level positions. This may impact the results of the study and should be taken into consideration when interpreting the findings.

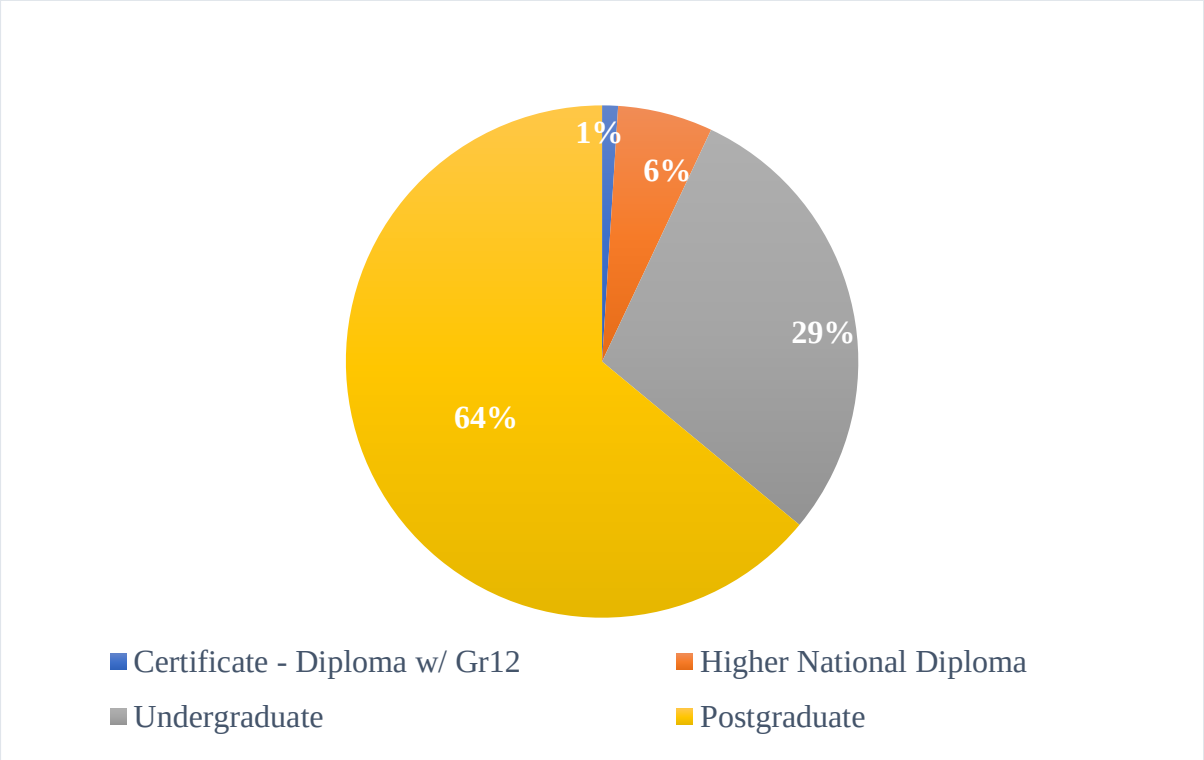


Figure 4.1 Educational Background of Home Developers

The findings from the descriptive analysis of the job positions of the representatives provide further perspectives into the sample population used in this study. Figure 4.2 shows that a significant proportion of the representatives (20%) hold directorial positions, while 42% of the participants held management roles. This suggests that the study was able to attract a sample population that is well-represented in decision-making positions within the affordable housing sector. This is important because their insights and opinions carry significant weight in shaping the future of the sector.

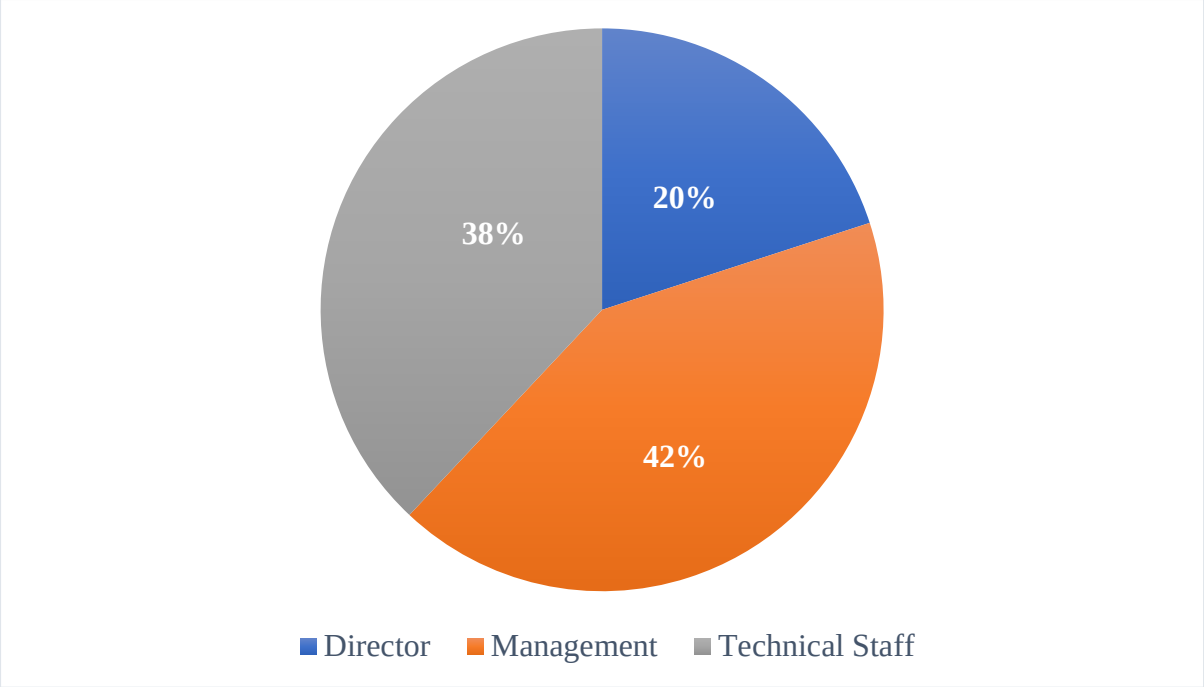


Figure 4.2 Designation of Representatives

Further breakdowns of job positions as shown in Figure 4.3 reveal the diversity of the sample population, with representation from various professions within the affordable housing sector. For example, 48% of the participants were engineers, 18% were architects, and 24% were construction managers. This diversity of perspectives provides a more comprehensive understanding of the challenges and opportunities within the affordable housing sector, as the experiences and insights of each profession add to the overall picture. In addition, the collection of data from other key stakeholders within the industry improved the calibre of responses, such as the remaining 7% and 3% being quantity surveyors and project managers. It also suggests that the study was able to reach a sample population that is representative of the sector, thereby increasing the validity and reliability of the findings.

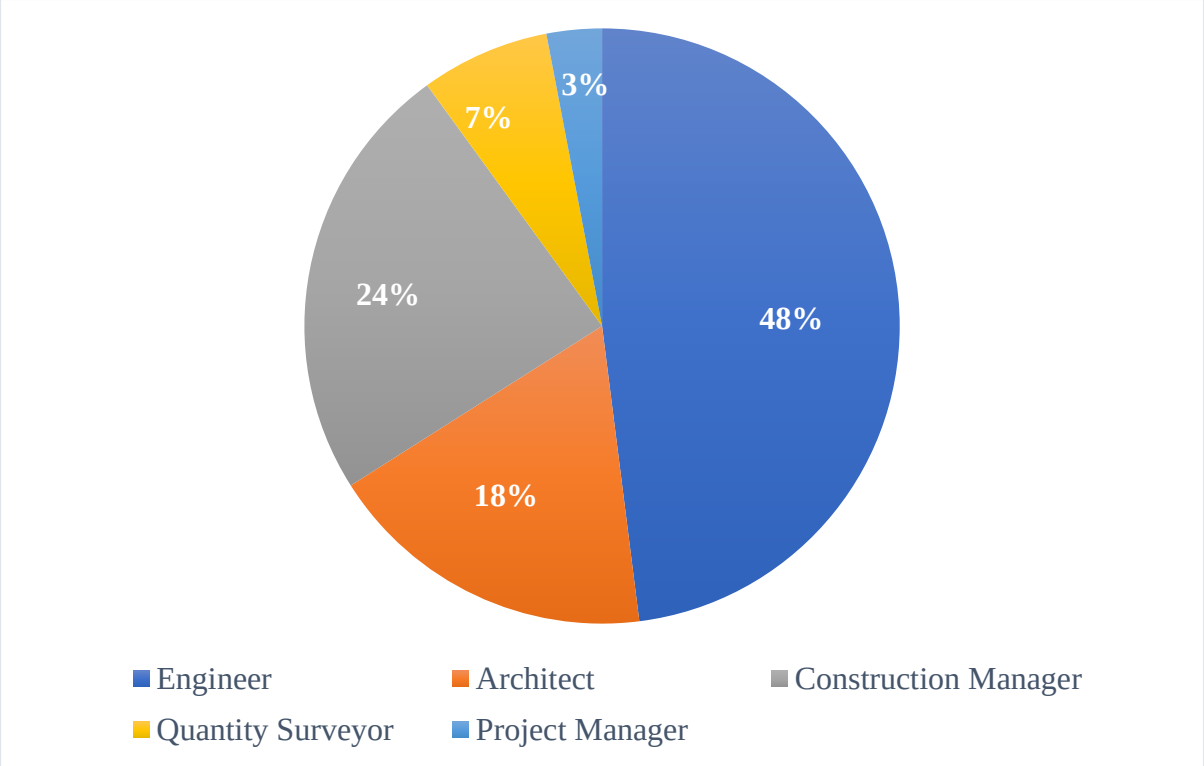


Figure 4.3 Distribution of Representative's Fields

The distribution of the representative's experience in affordable housing provides important information regarding their level of expertise in the field. As shown in Figure 4.4, it was found that the majority of the representatives (60%) had 5 or more years of experience in affordable housing, with 29% having 10 or more years of experience. This demonstrates that the sample population is composed of experienced professionals who have a substantial level of knowledge and understanding of the challenges and complexities of affordable housing. This information is particularly relevant in the context of the study, as the ability to understand the complexities and challenges of affordable housing is critical to the success of any initiatives or projects aimed at addressing the issue. The presence of experienced professionals in the sample provides valuable insight and understanding into the perspectives, attitudes, and experiences of those working in the field, which can be beneficial in identifying areas for improvement and in designing effective solutions. The findings of this theme highlight the importance of taking into account the expertise and experience of professionals in the field when making decisions and designing initiatives aimed at addressing affordable housing.

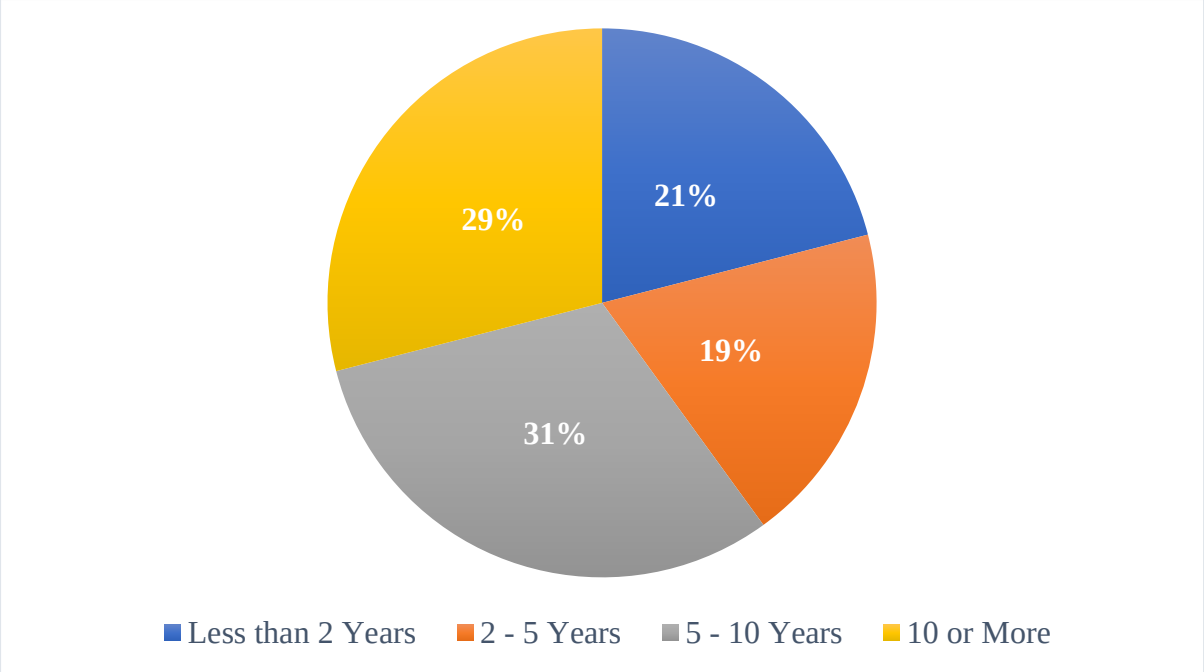


Figure 4.4 Representative's Years of Experience in Affordable Housing.

4.2.1.2 Background of Home Developer's Firms:

A deeper analysis of the firm history and services provided data can offer further insight into the experiences and capabilities of the participant firms. The majority of the firms (60%) have been established for over 10 years, which suggests that they have a wealth of experience and a proven track record within the industry. This experience can be seen as an advantage in delivering quality affordable housing services, as it demonstrates a level of stability and expertise. The longevity of these firms may also indicate their ability to adapt and overcome challenges in the market, further demonstrating their competence and reliability. The distribution of the firms' establishment years can also provide insight into the growth and development of the affordable housing industry. A higher number of firms established for more than 10 years suggests a relatively mature market, while a higher number of firms established for less than 5 years may indicate a growing market with new entrants. This information can be valuable for stakeholders seeking to understand the current state and future potential of the affordable housing industry.

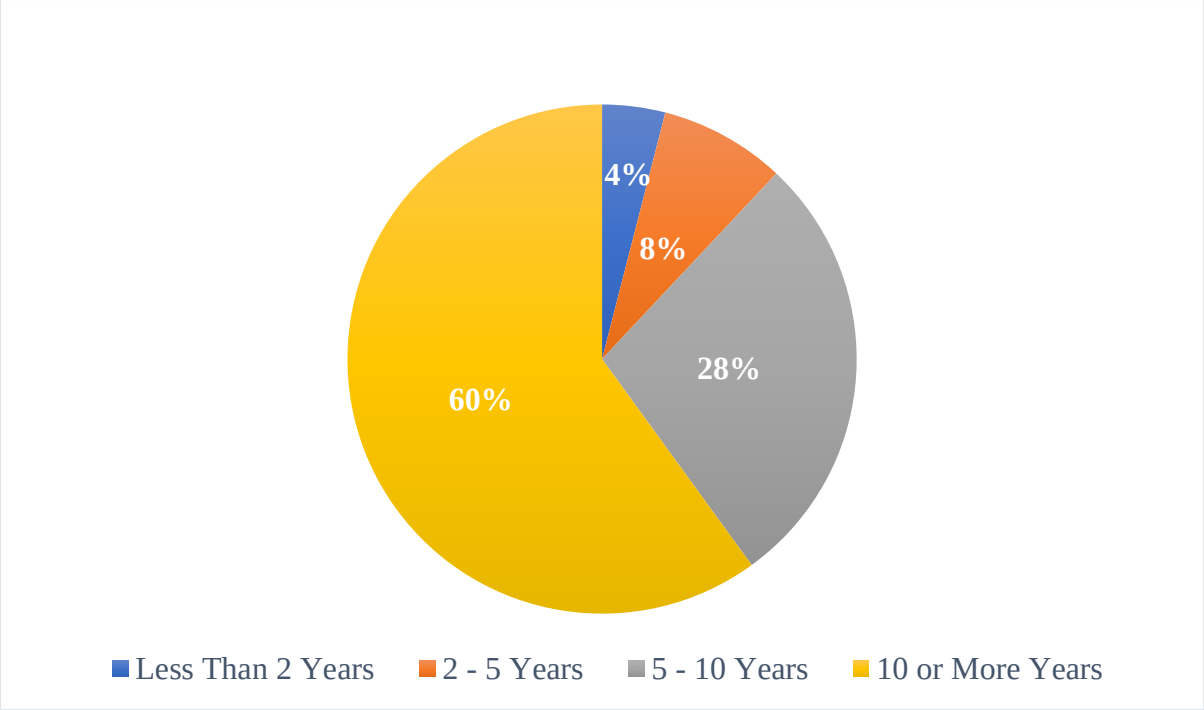


Figure 4.5 Years of Establishment of Firm.

While Figure 4.4 and Figure 4.5 show that the representatives have extensive experience in affordable housing, the findings suggest that this may not be the case for the firms they represent. This is evident in Figure 4.6, which indicates that 46% of the firms surveyed have delivered less than two affordable housing projects in the past five years, despite the majority of respondents having over five years of experience in the affordable housing sector. This suggests that the firms may have prior experience in other services and that affordable housing may be a new area of focus for these firms. However, the respondents themselves have experience in the affordable housing sector, which explains why they were chosen to participate in the survey. The findings related to the number of affordable housing projects delivered by the firms within the past 5 years provide important insight into the role that these firms are playing in addressing the affordable housing backlog in the country. As displayed in Figure 4.6, only 21% of the home developers reported delivering 10 or more affordable housing projects within the past 5 years, while 46% delivered less than 2 houses. This suggests a significant gap in the delivery of affordable housing by the firms represented in the sample. The importance of addressing the affordable housing backlog cannot be overstated, as it has been identified as a major issue in the country. The lack of affordable housing can lead to a range of negative consequences, including increased poverty and homelessness, and can also have a detrimental impact on the economy. Given the significance of the affordable housing issue, it is crucial that firms are actively engaged in addressing the backlog by delivering a higher number of affordable housing. The data presented in Figure 4.6 suggests that the firms represented in the sample may not be playing as active a role as they could be in addressing this critical issue. However, this is contrary to the current designation of the home developers surveyed who indicated that they have significant experience in affordable housing delivery. This indicates that their current firms simply don't provide enough affordable housing as much as previous firms they may have worked for, or within their past independent practices. The results of minimal firm involvement in affordable housing delivery, as displayed in Figure 4.6, further prove Mahachi's (2021) argument that the overall delivery of affordable housing in South Africa has decreased significantly from approximately 160,000 units completed in

2009/10 to just under 100,000 units completed in 2018/19. However, it is important to consider the reasons for this gap and to identify potential solutions that can help increase the delivery of affordable housing by these firms. This could include increased government support, incentivising the delivery of affordable housing, and providing training and resources to help firms increase their capacity to deliver affordable houses.

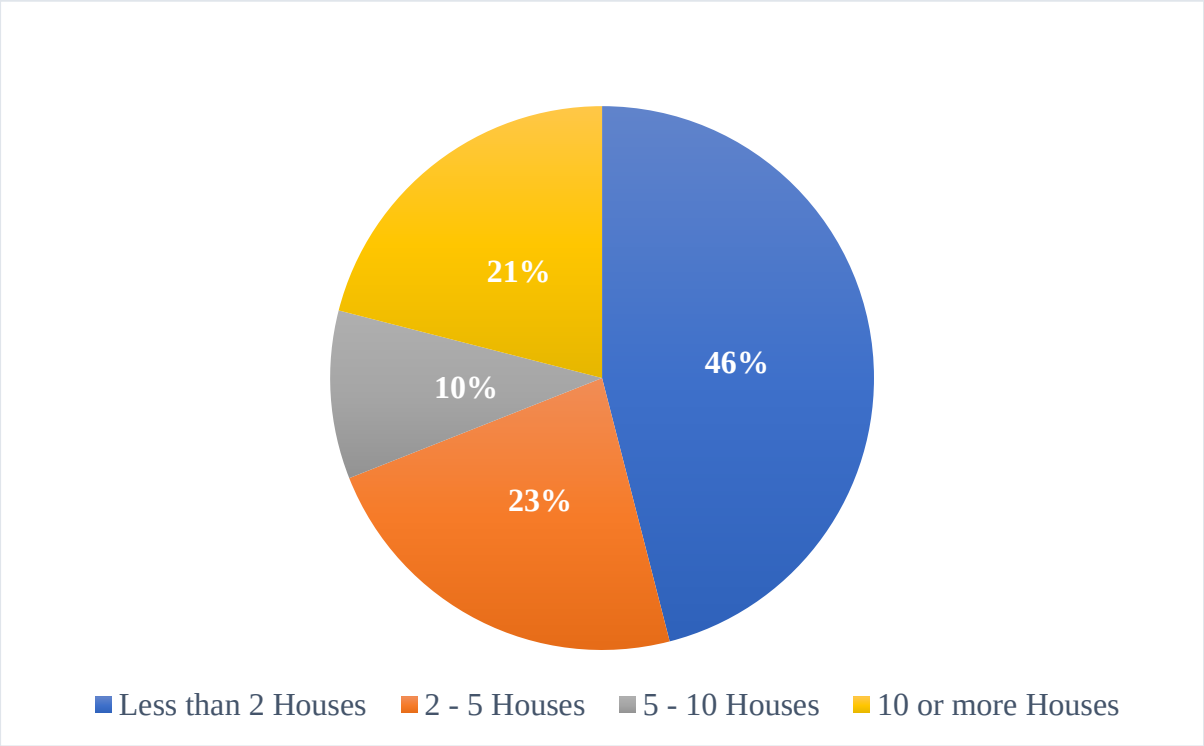


Figure 4.6 Number of Housing Projects Delivered by the Firm in the Past 5 Years

4.2.1.3 Home Developer's Technical Expertise in Affordable Housing:

The following section of the survey delved into the technical aspect of understanding representatives' views on innovative technology within the affordable housing market. The survey began by gauging a consensus on the representative's perception of whether the lifecycle costs of South African affordable housing are truly affordable for low-middle-income households.

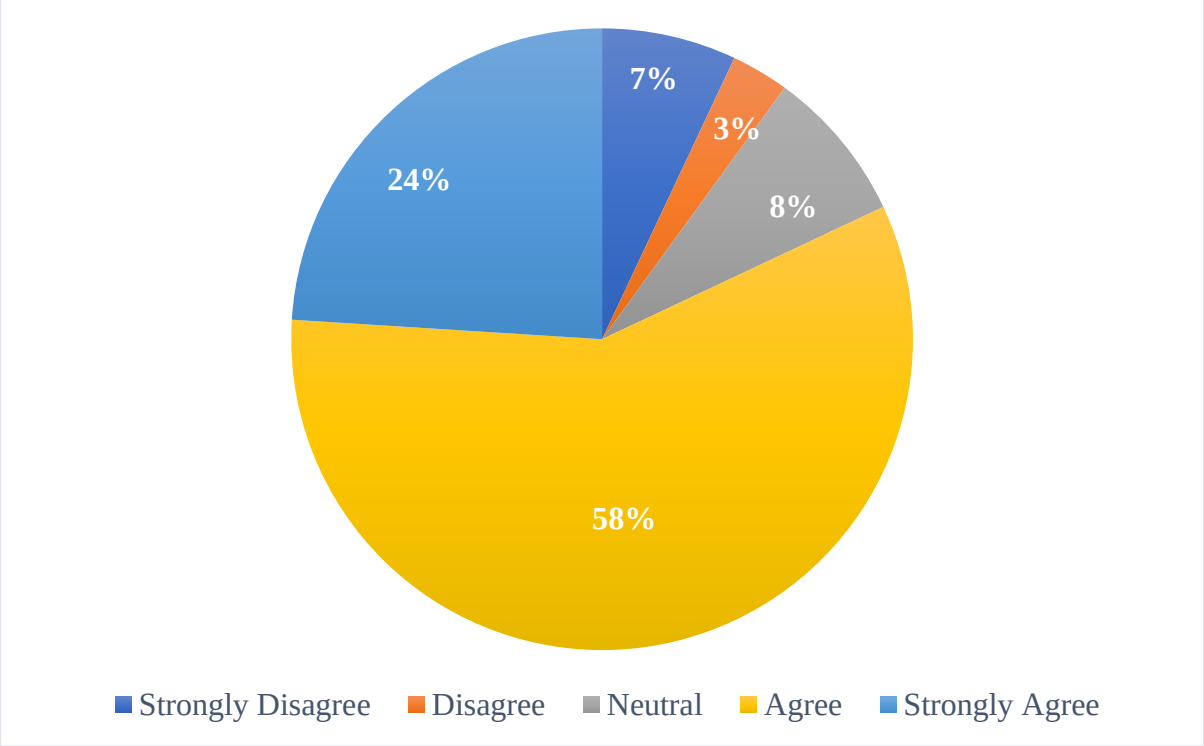


Figure 4.7 Home Developer's Opinions on Affordability of South African Affordable Housing Lifecycle Costs.

Based on the distribution of responses shown in Figure 4.7, it is evident that there is a significant concern among home developers regarding the affordability of South African affordable housing lifecycle costs. A majority of representatives (58%) agree that the lifecycle costs of affordable housing are unaffordable for low-middle-income households. This indicates a prevailing issue in the market that needs to be addressed. It is important to note that a notable proportion of representatives (24%) remained neutral in their opinion. This suggests that there is a need for further exploration and discussion to fully understand the challenges and issues related to the affordability of affordable housing in South Africa. Upon analysing the survey results seen in Figure 4.8, it becomes clear that the high costs of building materials and prolonged durations between conception and construction are considered as the primary factors contributing to the unaffordability of affordable housing lifecycle costs. These findings highlight the significance of addressing rising construction costs and improving project delivery efficiency within the affordable housing sector.

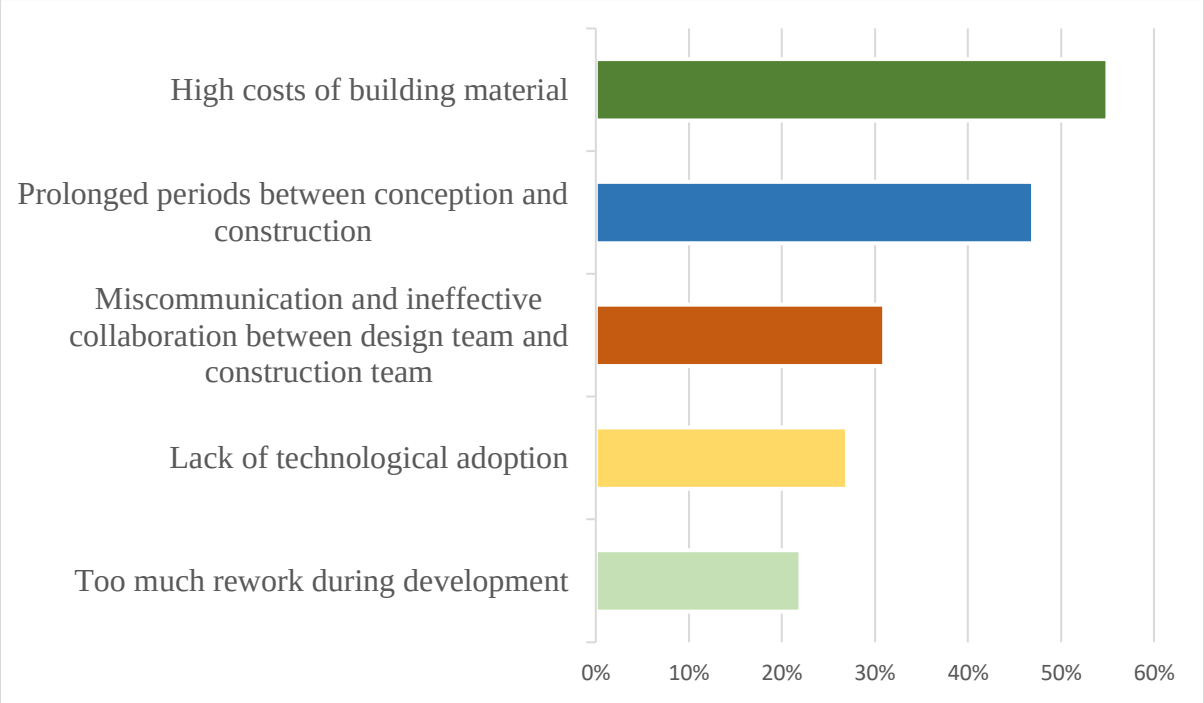


Figure 4.8 Factors Contributing to the High Lifecycle Costs of South African Affordable Housing According to Home Developers.

Additionally, the data in Figure 4.8 identifies a smaller but significant proportion of home developers that believe the lack of technology adoption and awareness, too much rework during development, and miscommunication and ineffective collaboration between the design team and the construction team also contribute to the high lifecycle costs of SA affordable housing. This emphasises the need for increased adoption and understanding of innovative technologies, more efficient and streamlined processes in construction, and better communication and collaboration between all stakeholders in the affordable housing market.

4.2.1.4 Assessing Representatives' Perceptions of Delays in South African Affordable Housing Development

The next section of the survey sought to assess representatives' perceptions of the frequency of delays in the development of South African Affordable housing. The statement presented to representatives was "Delays in the development of South African affordable housing are a recurring event."

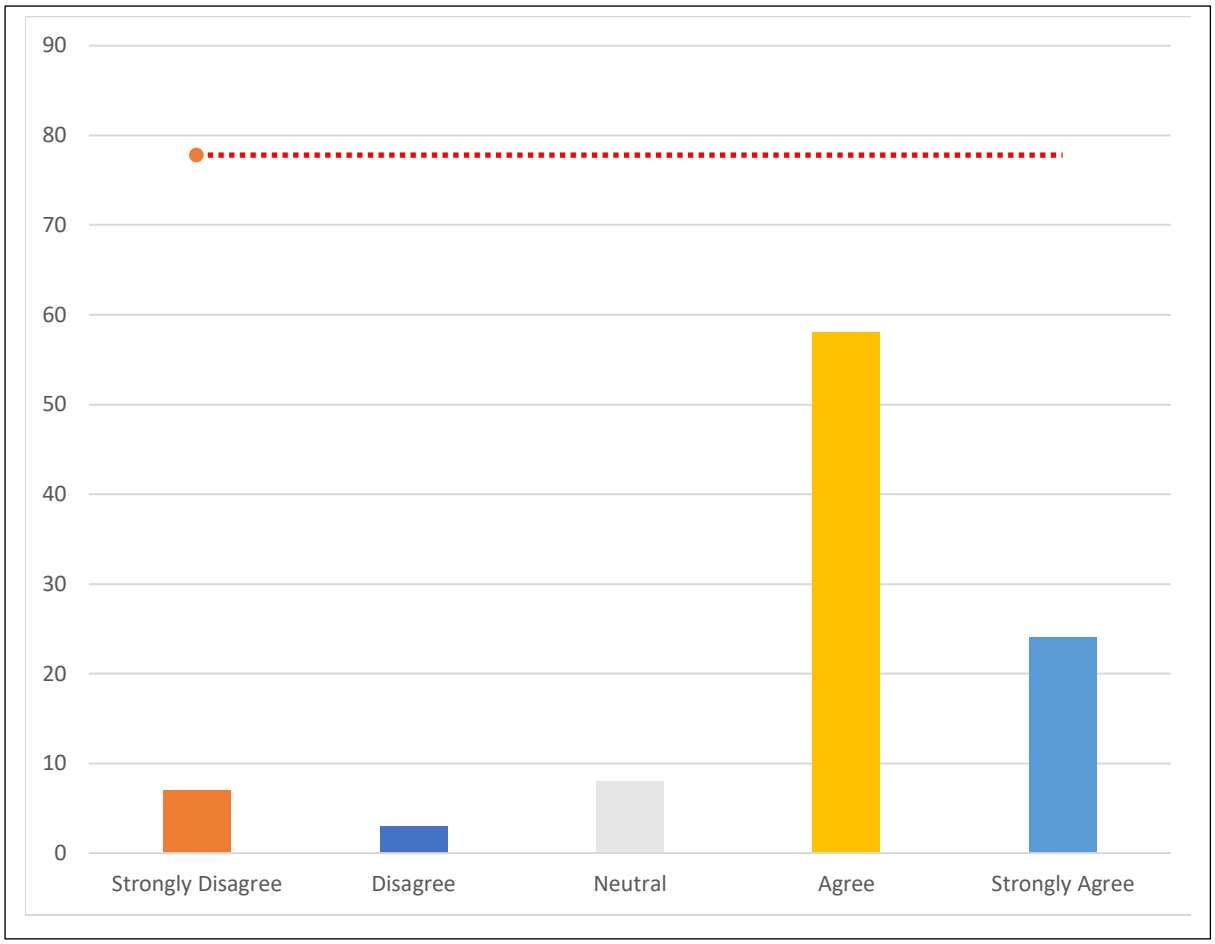


Figure 4.9 Extent of Agreement Among Home Developers on the Recurrence of Delays in the Development of South African Affordable Housing

The data presented in Figure 4.9 reveals the extent of agreement among home developers regarding the recurrence of delays in the development of South African affordable housing. An RII value of 77,8% was calculated, indicating that the respondents swayed towards agreeing with the statement that delays in the development of South African affordable housing are a recurring event. In addition, the actual responses indicate that the majority of respondents (82%) either agree or strongly agree that delays in the development of affordable housing are a significant challenge. This high level of agreement highlights the prevalence of this issue within the sector. It underscores the need for concerted efforts to address and mitigate these delays in order to improve the efficiency and timeliness of affordable housing delivery in South Africa. By acknowledging and taking steps to overcome these challenges, stakeholders can work towards providing affordable housing solutions more effectively, meeting the growing demand, and ensuring timely access to affordable housing for those in need.

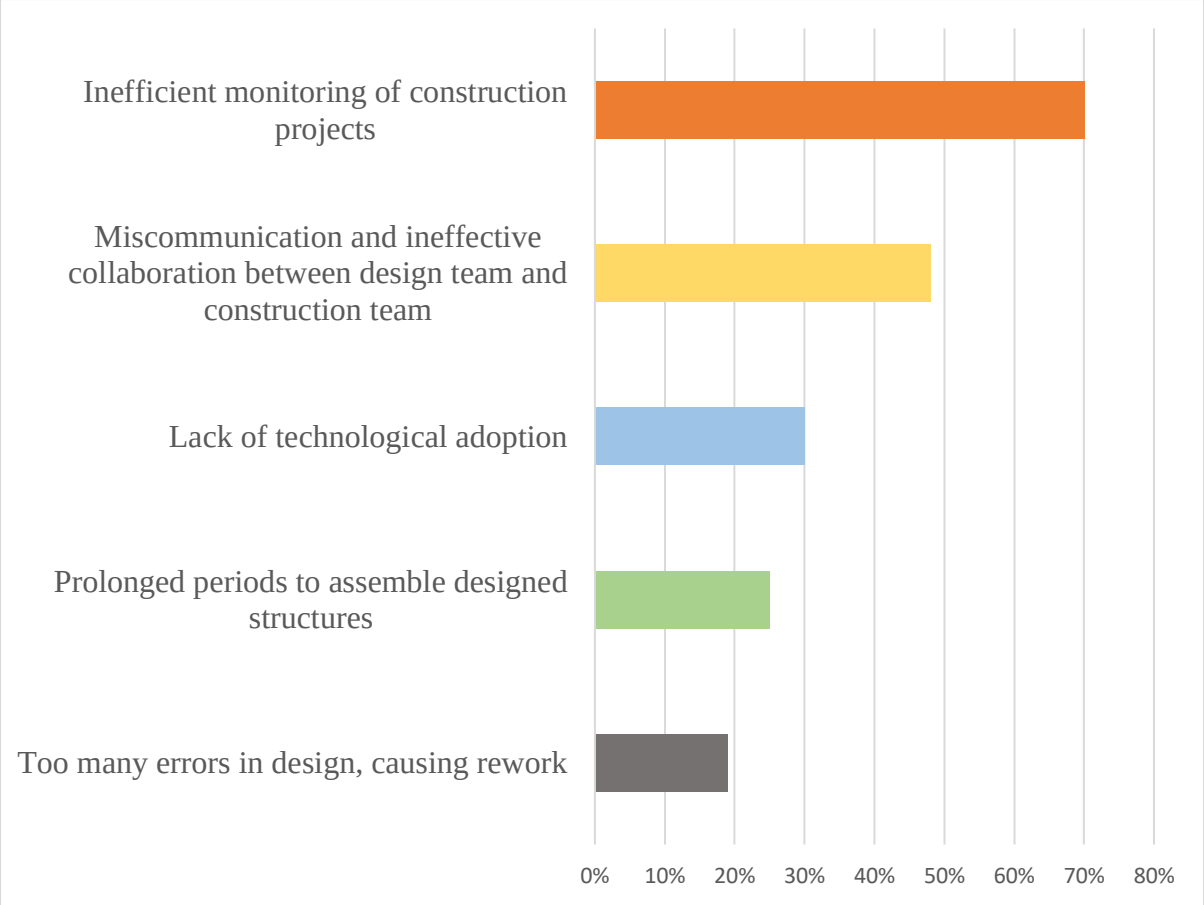


Figure 4.10 Analysis of the Factors Responsible for Delays in the Construction and Delivery of South African Affordable Housing.

The findings demonstrated in Figure 4.10 from the representatives regarding the causes of delays in South African affordable housing delivery indicate a complex and multi-layered understanding of the problem. Most home developers (70) believe that inefficient monitoring of construction projects is the primary cause of delays, highlighting the importance of effective project management and oversight. However, other factors such as miscommunication and ineffective collaboration between the design and construction teams, lack of technology adoption, prolonged periods to assemble structures, lack of technological awareness, and errors in material design leading to rework were also identified as contributing factors. These findings suggest that addressing delays in affordable housing delivery requires a comprehensive approach, which considers the interplay of multiple factors, including efficient project management, effective communication and collaboration, adoption of innovative technologies, and reducing errors and rework. The results provide important insights into the challenges faced by the affordable housing market in South Africa and the need for a multi-faceted solution to address the issue.

4.2.1.5 Representatives' Perceptions of Technology Adoption for Affordable Housing Design and Construction

The final topic addressed within this section aimed to understand what the representatives may believe are some of the potential advantages of technology adoption during the design and construction of affordable housing. In order to gain a comprehensive understanding of the representative's perspectives, they were given the option to select multiple responses.

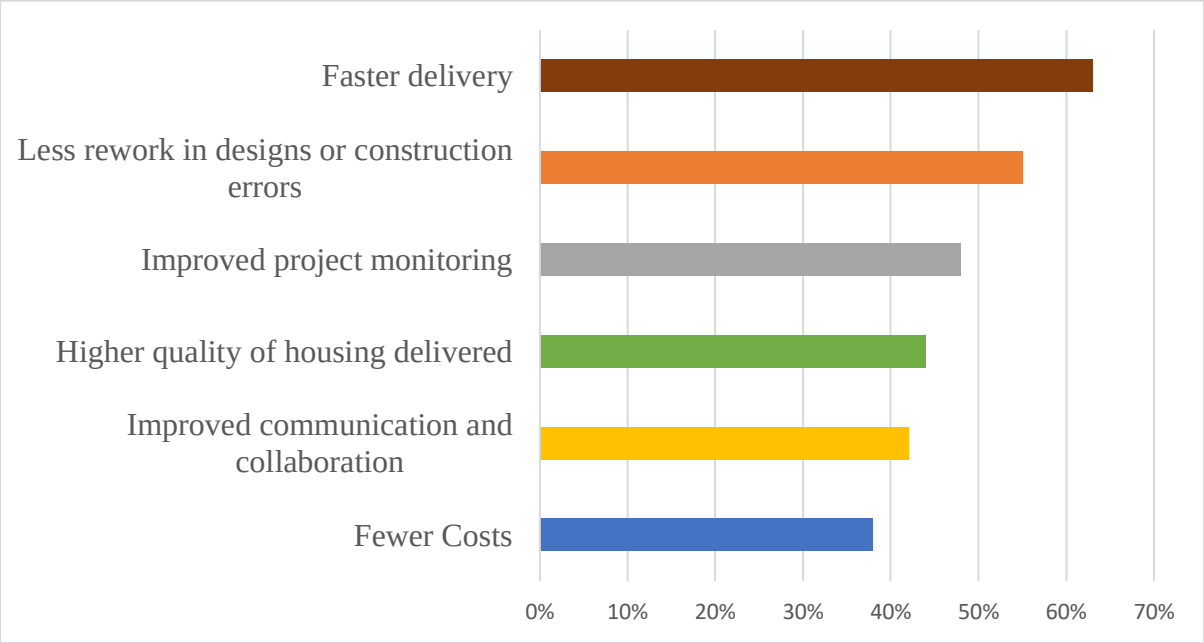


Figure 4.11 Exploring the Advantages of Integrating Technology in Affordable Housing Design and Construction

The results of the survey, as shown in Figure 4.11, suggest that most representatives believe that technology adoption can bring a range of benefits to the design and construction of affordable housing. The most cited advantage is that technology can lead to faster delivery of affordable housing projects, as 63% of representatives believe. This highlights the potential for technology to streamline project management and construction processes, which can help to address the affordable housing backlog in South Africa. Another key advantage of technology adoption, according to 55% of the representatives, is that it can result in less rework and fewer construction errors. This is crucial for ensuring the quality and accuracy of affordable housing projects, which can help to meet the needs of low-middle-income households. Additionally, 48 representatives believe that technology adoption can result in improved project monitoring, which can further contribute to the efficient delivery of affordable housing. 44 participants believe that technology adoption can result in improved housing quality, which is crucial for ensuring that low-middle-income households have access to sustainable and high-quality housing. Additionally, 38 representatives believe that technology adoption can result in lower costs, which can lead to more affordable housing for low-middle-income households.

Ultimately, the survey results of this technical section reveal a prevalent issue regarding the high lifecycle costs of affordable housing in South Africa, with 53% of representatives agreeing that these costs are not affordable for low-middle-income households. The RII value of 69.6% and 77.8% indicates moderate inequality in the distribution of responses. High costs of building materials were identified as the primary contributor to unaffordability. Lack of technology adoption, awareness, miscommunication, and ineffective collaboration were also contributing factors. These representatives recognised potential advantages of technology adoption, such as faster delivery, improved project monitoring, and fewer costs. The findings provide valuable

insight into the challenges facing the affordable housing market in South Africa and emphasise the need for increased technology adoption to address these issues.

4.2.1.6 Home Developer's Familiarity and Usage of Innovative Technologies

The last section of the survey sought to understand the level of familiarity and understanding that professionals in the affordable housing sector have with various innovative technologies. The representatives were asked to rate their level of familiarity with Building Information Modelling (BIM) technology, Geographic Information Systems (GIS), Smart sensors, 3D laser scanners, Drones, Modular construction, 3D Printing, Object-oriented programming, and Project Portfolio Management.

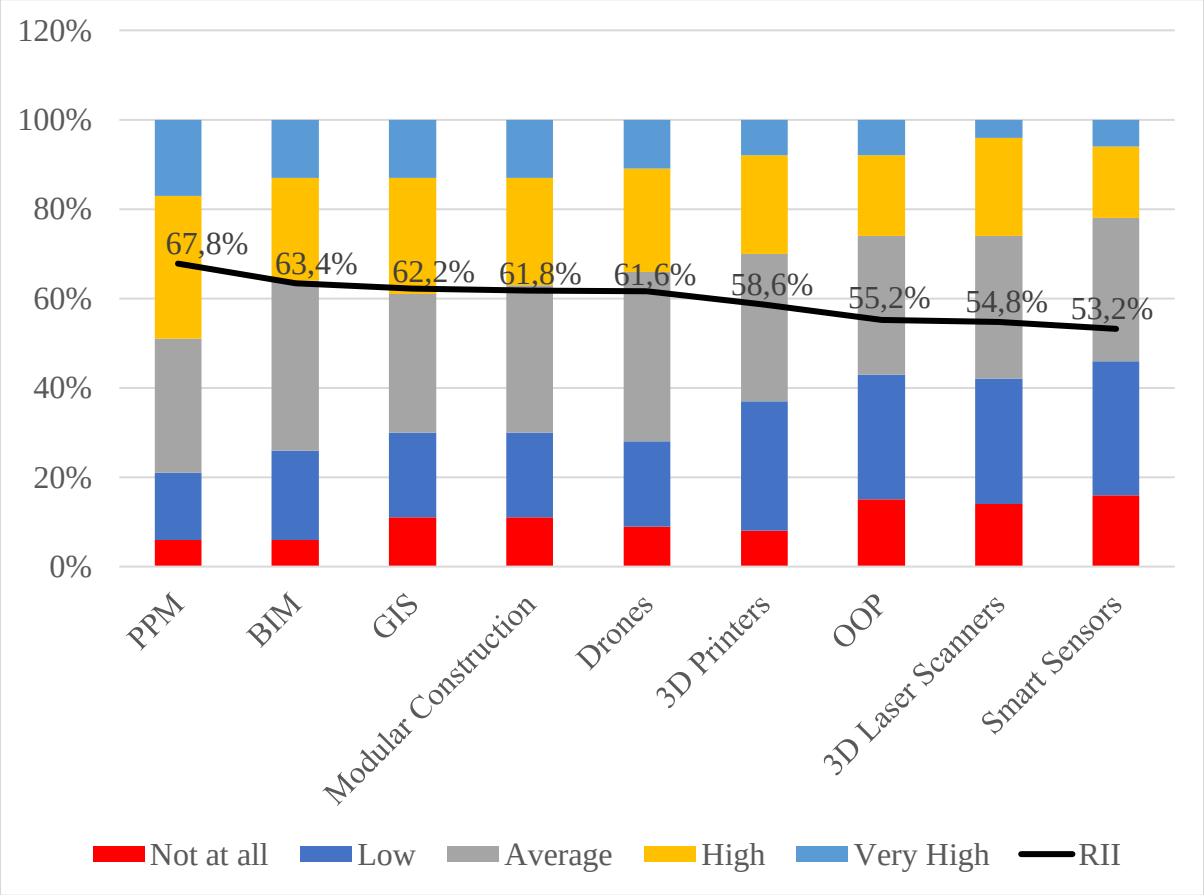


Figure 4.12 Participants' Level of Familiarity with The Following Technologies.

The survey findings depicted in Figure 4.12 indicate that the RII values represent the relative importance of each technology in terms of familiarity, with higher values indicating greater familiarity. Based on the data presented, Building Information Modelling (BIM) and Geographic Information Systems (GIS) are the two technologies with the highest levels of familiarity among the surveyed home developers, with RII values of 63.4% and 62.2%, respectively. The other technologies listed in the table, such as Smart Sensors, 3D Laser Scanners, Drones, Modular Construction, 3D Printers, Object Oriented Programming (OOP), and Project Portfolio Management (PPM), also exhibit varying levels of familiarity, ranging from 53.2% to 67.8%. However, it is worth noting that Smart Sensors had the lowest RII value of all the technologies listed, indicating that it is the least familiar technology among the surveyed home developers. This figure provides valuable insights into the level of familiarity that home developers have with different innovative technologies. The data can be used to

identify which technologies are most used in the affordable housing sector and which may require additional education and promotion to increase their adoption.

The following question in this survey delved into the use of various innovative technologies in the design and construction of affordable housing projects. The representatives were asked to indicate their level of use on a scale, and the data were analysed using the RII metric as represented in Figure 4.13.

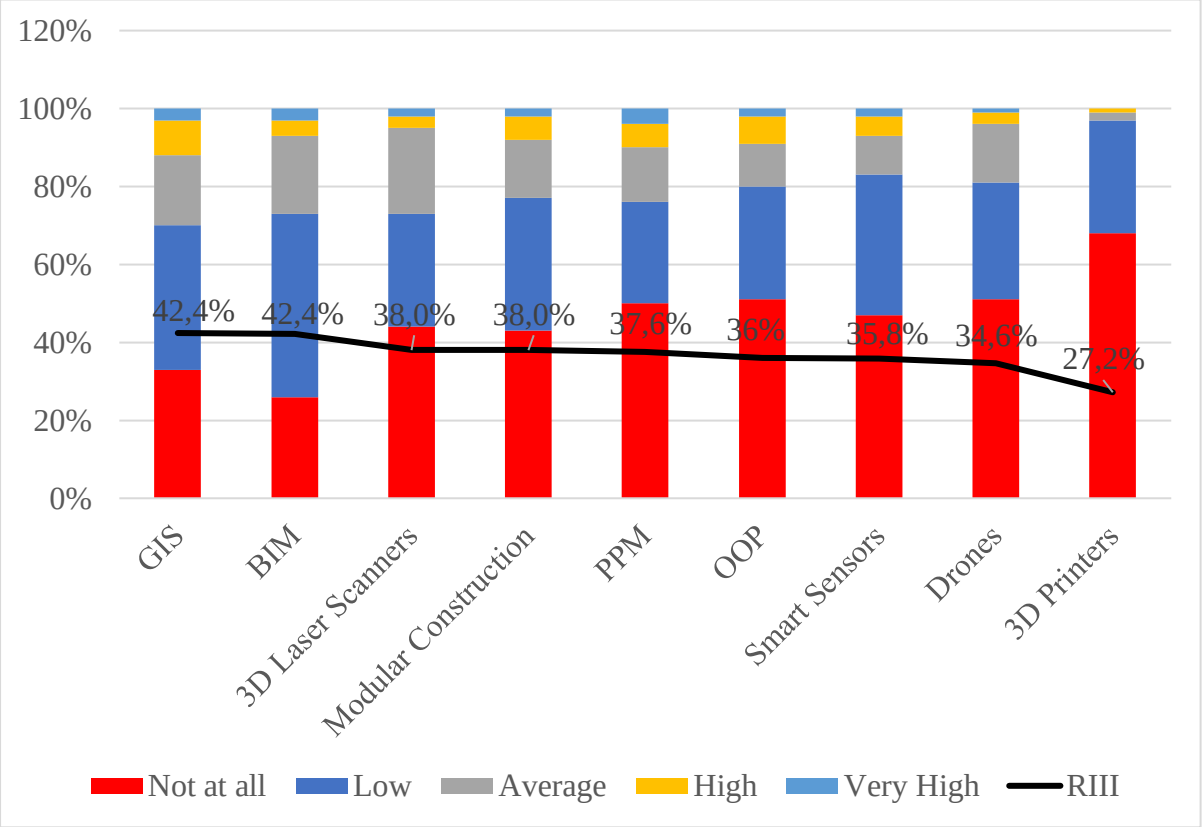


Figure 4.13 Participants' Usage of Innovative Technology in the Design and Construction of Affordable Housing.

Based on the collected data on the usage of innovative technology within home developers' projects, the RII values indicate that Geographic Information Systems (GIS), BIM, 3D laser Scanners, and Modular Construction have the highest levels of relative importance, with 42.4%, 42.2%, 38% and 38% respectively. Although these technologies have the highest RII values, in the context of where they should be, these are relatively low, with the majority of representatives indicating they have average to low usage of these top three technologies. It is worth addressing that although BIM was reported as a technology with one of the highest familiarities among the respondents, it still faces relatively low usage, as seen with the RII value of 42,2% (highlighting the majority vote of low usage). Looking further at Figure 4.13, Project Portfolio Management, Object-Oriented Programming, Smart Sensors, Drones and 3D Printers are among the least used technologies by home developers, with the majority indicating that they have never used them in their projects, as reflected by their lower RII values of 37.6%, 36%, 35.8%, 34.6% and 27.2% respectively. It is noteworthy that the RII values indicate the relative importance of the technologies concerning the outcome variable, which is the delivery process and affordability of South African affordable housing. Overall, the findings suggest that while home developers may be familiar with these innovative technologies, the majority of home developers are not fully utilising them in the design and

construction of affordable housing. This is clearly seen in the data, indicating that the majority state an extremely low usage of each technology. Thus, there is significant potential for increased utilisation of innovative technologies in the affordable housing sector in South Africa, which could lead to improved efficiency, quality, and affordability of housing delivery, ultimately addressing the housing crisis in the country. However, until further utilisation is adopted, issues as seen in Figure 4.10 will commence because of minimal innovation in affordable housing delivery.

4.2.1.7 Analysing the Impact of Innovative Technology on the Delivery and Affordability of Affordable Housing Projects: Participant's Perspectives

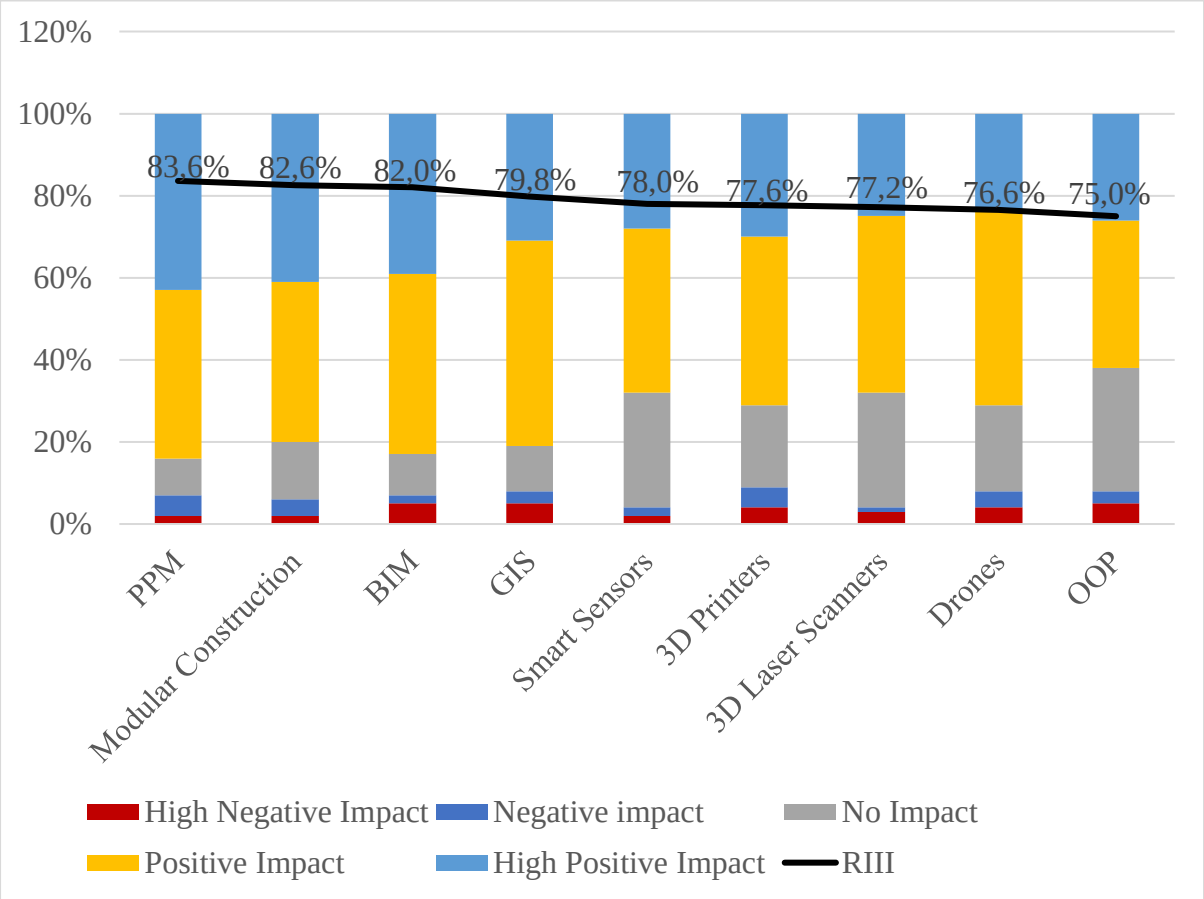


Figure 4.14 Perceived Impacts of Innovative Technology on Delivery of SA Affordable Housing by Surveyed Representatives.

The representatives were asked to indicate their level of agreement on the positive impact of innovative technologies mentioned earlier as displayed in Figure 4.14. The RII values range from 75% to 83.6%, indicating that all the technologies have a significant impact on the delivery process of affordable housing in South Africa. Building Information Modelling (BIM) and Project Portfolio Management (PPM) had the highest RII values, at 82% and 83.6%, respectively, indicating that these technologies have the most positive impact on the delivery process of affordable housing. Geographic Information Systems (GIS), Smart Sensors, 3D Laser Scanners, Drones, Modular Construction, 3D Printers, and Object-Oriented Programming (OOP) also had high RII values, ranging from 75% to 79.8%. The high RII values suggest that adopting these innovative technologies can significantly improve the efficiency, affordability, and quality of affordable housing delivery in South Africa. The results of this study provide important insights for policymakers, practitioners, and researchers, as they

can use these findings to prioritise interventions and allocate resources accordingly to enhance the delivery and affordability of affordable housing in South Africa.

The survey's final question asked the representatives to rate the impact that adopting innovative technologies would have on South African affordable housing costs. Figure 4.15 shows the relative importance index (RII) values for the impacts of adopting various innovative technologies on the costs of South African affordable housing. The RII values range from 68.2% to 79.8%. The technology with the highest RII value is Modular Construction, with a value of 78.4%. This indicates that adopting this technology is perceived by respondents as having the greatest impact on reducing the costs of South African affordable housing. Building Information Modelling (BIM) and Project Portfolio Management (PPM) also have high RII values, with scores of 75.8% and 79.8% respectively, suggesting that they have a significant impact on reducing costs. On the other hand, the technology with the lowest RII value is Smart Sensors, with a value of 68.2%. This indicates that respondents perceive Smart Sensors as having the least impact on reducing costs. The other technologies, including GIS, 3D Laser Scanners, Drones, 3D Printers, and Object-Oriented Programming (OOP), also exhibit moderate levels of impact on reducing costs, with RII values ranging from 68.2% to 76.0%. While the majority of the surveyed representatives believe that using these technologies would reduce costs, it's important to consider potential drawbacks and negative impacts as well.

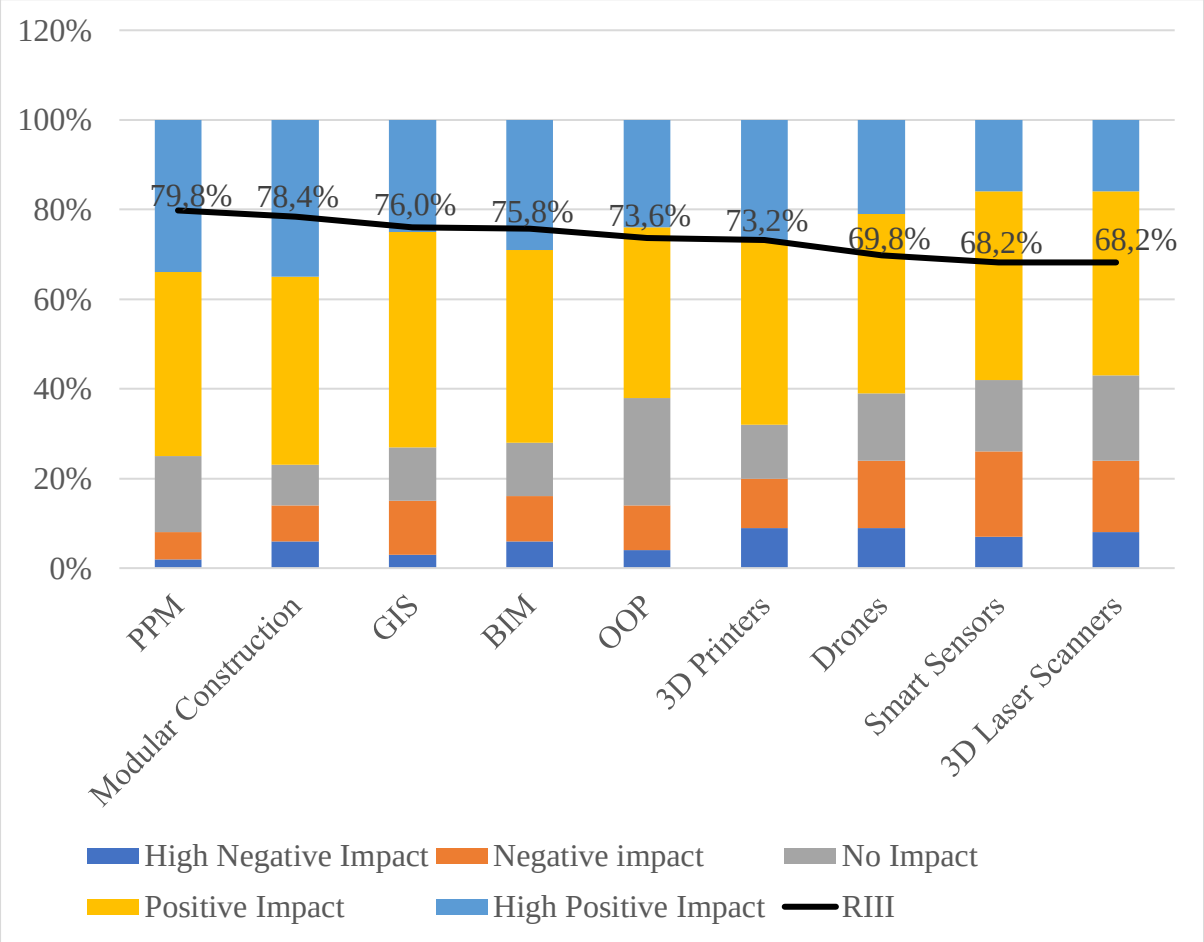


Figure 4.15 Participant Views on the Effects of Innovative Technology on South African Affordable Housing Costs.

4.2.1.8 Challenges and Barriers to Adoption of Innovative Technologies in Affordable Housing

Table 4.1 Challenges and Barriers to Adopting Innovative Technologies in Affordable Housing Design and Construction – Representative's Responses.

Challenges and Barriers	BIM	GIS	Smart Sensors	3D Laser Scanners	UAVs	Modular Construction	3D Printers	OOP	PPM	Overall
Lack of Technical Knowledge	57%	45%	48%	44%	42%	33%	44%	43%	42%	44%
High costs (Initial / maintenance /operation)	38%	30%	37%	43%	45%	28%	37%	20%	23%	33%
Lack of guidelines and standards	27%	35%	16%	22%	29%	29%	18%	30%	33%	26%
Lack of awareness of availability	18%	22%	26%	33%	22%	30%	26%	32%	20%	25%
Lack of incentives	17%	21%	18%	17%	20%	25%	22%	17%	19%	20%
The tendency to maintain current technologies	16%	16%	10%	12%	13%	19%	16%	18%	25%	16%
Unaware of this technology	13%	10%	27%	17%	9%	13%	17%	25%	11%	16%
Lack of policy and regulation	8%	12%	8%	6%	16%	12%	8%	8%	19%	11%
Incompatibility with other technologies	6%	9%	10%	6%	4%	14%	12%	7%	8%	8%

Table 4.1 illustrates the challenges and barriers associated with the adoption of innovative technologies in affordable housing design and construction. In addition, an overall average value was also calculated to give a further analysis of the overall challenges and barriers to innovative technology adoption, the same principle was applied to calculate the over level of the challenges and barriers per each technology. Representatives identify that the top three challenges faced with adopting innovation in construction are a result of lack of technical knowledge, high costs of adoption, maintenance, and operation, and lastly, the lack of guidelines and standards involved with new technologies. Once considering these factors, it makes it easier to understand the minimal adoption of these technologies. With a focus on each challenge and barrier, most of the representatives believe that in South Africa there is less technical knowledge around technologies such as BIM (57%), Smart Sensors (48%), GIS (45%), 3D Scanners (44%) and 3D Printers (44%). Although most of the surveyed home developers have a fair understanding of the technologies mentioned, awareness of the technology and actual implementation knowledge are two different factors. The adoption of innovative technology requires extensive training, especially these complex technologies already stated by the representatives. Respondents identified high adoption, maintenance, and operational costs as significant challenges to innovative technology adoption. Interestingly, the same technologies with high adoption and maintenance costs are those that the home developers report using less frequently, as indicated in Figure 4.11. For instance, the most expensive technologies include 3D Laser scanners (43%), Drones (45%), 3D Printers (37%), and Smart Sensors (37%). Similarly, fewer than 5% of home developers use these technologies.

While the high cost of adoption and lack of technical knowledge are recognised as significant challenges to the adoption of innovative technologies, there are further considerations to be taken into account. A majority of the respondents (35%, 33%, 30%, 29%, and 27%, respectively) indicate that technologies such as GIS, PPM, OOP, Drones, and BIM have minimal standards and guidelines in South Africa to aid in their effective usage. This creates a barrier for companies that aim to use these technologies but cannot identify regulatory guidelines to successfully incorporate them into their practices. Additionally, while Figure 4.13 shows that these representatives have a fair knowledge of these technologies, they do identify that the general population may struggle with awareness of their availability due to limited supply within the country. This is evident with 3D Printing (26%), as there are currently a few operating 3D printers within the country. Similarly, the surveyed home developers identify technologies such as 3D Laser Scanners (33%), OOP (32%), and Modular Construction (30%) as having limited awareness of availability. Ultimately, the data in Table 4.1 suggests that significant challenges and barriers are faced by representatives in adopting innovative technologies in affordable housing design and construction. These challenges include high costs, lack of technical knowledge, lack of guidelines and standards, incompatibility with other technologies, lack of awareness of availability, lack of policy and regulation, lack of incentives, and a tendency to maintain current technologies. Policymakers, practitioners, and researchers can use this information to prioritise interventions and allocate resources to address these challenges and barriers to promote the adoption of innovative technologies in affordable housing design and construction.

In conclusion, this study has provided valuable insights into the perceptions and attitudes of home development company's representatives towards the potential of innovative technology to improve the delivery and costs of affordable housing projects in South Africa. The results indicate a high level of consensus among the representatives that the adoption of these technologies will have a positive impact on affordable housing. While challenges exist, most innovative technologies were found to have highly positive impacts on the delivery and affordability of affordable housing, with BIM, GIS, and Modular Construction showing the

highest impacts. To further support these findings, inferential statistics can be used to analyse the data and test for significant differences and relationships between variables. This can provide a deeper understanding of the factors that may influence the adoption and implementation of these technologies in the affordable housing sector. By using inferential statistics, we can draw more robust conclusions and make informed recommendations for future research and policy decisions.

4.2.1.9 Examining the Role of RII in Evaluating the Impact of Innovative Technologies on Affordable Housing Delivery and Affordability

The first initial RII values calculated from the survey RII values were calculated to provide a robust overview of the data. RII values measure the relative importance of survey questions in relation to the outcome variable, which in this case is the delivery process and affordability of South African affordable housing. The first RII value was calculated to gauge the representatives' views on whether the lifecycle costs of South African affordable housing are affordable for low-middle-income households. The RII value of 0.696 indicated that the perceived affordability of affordable housing is a significant challenge faced by low-middle-income households, as reported by the home developers who strongly agreed with this statement. Therefore, addressing affordability is crucial to improving the efficiency and affordability of affordable housing delivery. The second RII value of 0.778 was calculated to assess the representatives' views on whether delays in the development of South African affordable housing are a recurring event. The high RII value indicates that delays in the development of affordable housing are perceived as a significant issue that needs to be addressed urgently. This highlights the need for interventions that can improve the efficiency of the delivery process of affordable housing projects.

Further in the survey, more detailed RII values were calculated based on the responses that generated categorical answers. These RII values provide valuable insights into the current state of innovative technology adoption in the affordable housing sector in South Africa. With regards to the home developer’s responses on the level of familiarity, and usage of innovative technologies in affordable housing design and construction, The results reveal that several technologies such as Project Portfolio Management, BIM, GIS, Modular Construction, and Drones have moderate to high RII values above 60%, indicating that the majority of participants have a high to very high understanding of them. In contrast, participants have a moderate level of knowledge about technologies such as 3D Printers, Object Oriented Programming, 3D Laser Scanners, and Smart Sensors. These findings suggest that additional support, training, and education may be necessary to help home developers fully understand the potential benefits of these technologies in affordable housing design and construction.

However, there is a contrast when monitoring the level of usage of similar technologies. GIS and BIM show the highest level of usage (42.4% and 42.2%, respectively) compared to other technologies. However, in the overall scheme, the adoption rate of these technologies remains low, with various home developers reporting a lower level of usage of GIS and BIM. This trend is common among other technologies, with an average of close to 50% of respondents indicating that they do not use technologies such as 3D Laser Scanners, Modular Construction, Project-Portfolio Management, Object-Oriented Programming, Smart Sensors, Drones, and 3D Printers. Consequently, the remaining technologies report lower RII values. Notably, 3D Printing reports the lowest usage with an RII value of 27.2%, which correlates with the technology's infancy in South Africa, and thus, only a few individuals have come in contact with it. These low usage reports highlight the barriers to the adoption and implementation of these technologies by home developers. The study highlights the significant potential for

increased utilisation of innovative technologies in the affordable housing sector in South Africa. The adoption of these technologies could lead to improved efficiency, quality, and affordability of housing delivery, which are critical factors in addressing the housing crisis in the country. The findings suggest that policies and incentives may be necessary to encourage home developers to adopt and implement these technologies, along with additional support, training, and education to help them fully realise the benefits.

Further analysis of the home developers' responses concerning these technology's impact on the delivery and affordability of innovative technology reveal noteworthy data. Building Information Modelling (BIM) and Geographic Information Systems (GIS) were found to have the highest impacts on the delivery and affordability of affordable housing, with RIIs of 82% and 79.8%, respectively, for delivery, and RIIs of 75.8% and 76% for affordability, respectively. Modular Construction was also found to have a highly positive impact on both delivery and affordability, with RIIs of 82.6% and 78.4%, respectively. However, Smart Sensors and 3D Laser Scanners were found to have slightly lower impacts on the affordability of affordable housing, with RIIs of 68.2% for both technologies. Similarly, Drones were found to have an RII of 69.8% for affordability. 3D Printers had the highest RII for affordability after BIM, GIS, and Modular Construction, with an RII of 73.2%. This data suggests that the adoption of innovative technologies has the potential to enhance the delivery and affordability of affordable housing in South Africa. The impacts on delivery and affordability vary across different innovative technologies, with some technologies exhibiting higher impacts than others. Policymakers and practitioners in the affordable housing sector can use this information to prioritise interventions and allocate resources to promote the adoption of innovative technologies that have the highest potential to enhance the delivery and affordability of affordable housing.

The results from the inferential statistics analysis using the RII statistical method reveal the critical role that innovative technologies can play in the delivery and affordability of affordable housing in South Africa. Building Information Modelling (BIM) and Geographic Information Systems (GIS) are identified as the most familiar and frequently used technologies, while Smart Sensors exhibit the highest challenge to adoption. The findings suggest that innovative technologies have significant potential to enhance the delivery and affordability of affordable housing, but there is a need for increased efforts to promote their adoption. The results have significant implications for policymakers, practitioners, and researchers in the affordable housing sector. By prioritising interventions, identifying key drivers, and developing strategies, policymakers and practitioners can promote the adoption of innovative technologies and enhance the efficiency, quality, and affordability of affordable housing delivery in South Africa. Furthermore, the study provides a basis for further research on the impacts of innovative technologies in the affordable housing sector.

4.3 Analysing the Qualitative Analysis:

The purpose of this thematic analysis is to explore and understand the experiences and perspectives of the participants regarding the use of technology in the construction industry. The steps involved in the thematic analysis stem from the definition coined by Braun & Clarke (2006), thematic analysis is a method for identifying, analysing, and reporting patterns (themes) within data. The data was obtained via in-depth, one-on-one interviews which were conducted with a limited number of participants until the point of saturation was reached. These participants included Experts, Academics and Policy Makers that have been involved in Affordable Housing or have a strong understanding and experience in this field. Each participant was given a variable association to assist with referencing within the thematic

analysis, for example, Experts would take on the code ‘E1’ or ‘E2’, Policy Makers would be ‘P1’ and so on, while Academics would be ‘A1’.

Table 4.2 Summaries of Interviewee’s Background

Group	Expert code	Education	Position
Experts	E1 - *Industry Expert*	Masters	Engineer
	E2 - *Industry Expert*	Masters	Housing Developer
	E3 - *Industry Expert*	Masters	Architect
Policy Makers	P1 - *Government Policy Maker*	Doctorate (PhD)	National Government Official
	P2 - *Home Development Policy Maker*	Doctorate (PhD)	Policy Maker
Academics	A1 - *Built Environment Academic*	Doctorate (PhD)	Researcher
	A2 - *Built Environment Academic*	Doctorate (PhD)	Professor

The data collected was analysed to identify recurring themes and patterns in the participants' responses. Based off the key findings, the major themes obtained from the study included “Benefits and Challenges of Innovative Technologies in Affordable Housing”, “Innovative Technology Adoption in South Africa”, “The Impact of Innovative Technology on Affordable Housing Delivery and Affordability”, and “Other Factors Affecting the Affordable Housing Sector in South Africa”. With such insight, the analysis can gain deeper knowledge into the participants' perspectives and provide a rich description of their experiences with the use of technology in construction. The results of this analysis will add valuable information to the existing body of knowledge in the field and provide a comprehensive understanding of the experiences and perceptions of the participants. When looking at the themes generated from the thematic analysis, Figure 4.16 summarised the themes that were generated from the actual Node Tree captured in NVivo which can be viewed in Appendix H.

Theme 1: Factors Affecting the Affordable Housing Sector in SA

- Challenges Associated with Affordable Housing Definition
- Housing Backlog Crisis on South African Society

Theme 2: Affordable Housing Issues and Possible Remedies

- Advantages of Innovative Technologies in Affordable Housing
- Challenges of Affordable Housing Development and Delivery
- Disadvantages of Innovtive Technologies in Affordable Housing
- High Costs of Innovative Technologies
- Over Crowding

Theme 3: Innovative Technology Adoption in South Africa

- Challenges and Barriers of innovative Technology Adoption in SA
- Construction Industry's Slow Innovative Technology Adoption
- Government Supprort of Innovative Technology Implementation
- Impact of Innovative Technology on Job Security in SA
- Innovative Technology Adoption in South Africa
- Insufficient Contractor Skill Levels
- Lack of Innovative Technology Awareness
- Social Acceptance of Innovative Technology
- The Role of Innovative Technology in the Participant's Practices

Theme 4: Impact of Innovative Technology on Affordable Housing Delivery

- Impact of Innovative Technologies on Affordable Housing Delivery
- Impact of Innovative Technology on Affordable Housing Costs and Affordability
- Long Run Cost Saving of Innovative Technologies
- Reasons in Delay and Cost Overruns
- Unaffordability of Affordable housing

Figure 4.16 Parent and Child Nodes Generated from Thematic Analysis

Ultimately, Figure 4.16 was used to identify relevant trends in the themes presented from the code generation, which helped to guide the analysis and synthesis of the findings.

4.3.1 Theme 1: Factors Affecting the Affordable Housing Sector in South Africa

4.3.1.1 Challenges Associated with Affordable Housing Definition

In the thematic analysis, the initial step involved inviting participants to identify challenges with affordable housing delivery. Some participants provided a brief overview of affordable housing before delving into challenges, highlighting the relative nature of the topic. For example, E3 noted that *"affordable may mean different things to different people".* Setting a

clear definition of affordable housing sets a clear direction of how the participants further intended to answer the remaining interview questions. Similarly, the definitions from the participants closely related to the definitions provided in the literature. P2 identified that as it stands, the government make large claims about affordable housing, yet there is no formal definition that policymakers can stand by. P2 has derived a definition based on components such as the Finance Linked Individual Subsidy Programme (FLISP). P3 identifies that this program is aimed at aiding potential homeowners have access to their own affordable homes, P2 defines the households that qualify for this program as:

"People who are too rich to get a government subsidy are people who are too poor to get a home loan on their strength."

This definition is upheld by policymakers who chose to define affordable housing in a similar manner. P2 identifies that the households that qualify for the FLISP project are households that fit into the affordable housing definition as this program was aimed at helping people who have financial constraints in securing funds for housing or deposits for housing. A1 further looks at the definition and derives the definition based on a household's income category. A1 argues that if a household earns R15,000 or less, then that household qualifies for the FLISP project. This value can be based on E3's view that housing costs should not exceed 30% of the household's income, otherwise, the housing situation is not affordable. As a result, if a household earns R15,000 or less, housing costs higher than 30% will exceed their ability to pay for other necessities. Such claims can be represented in E3's statement, arguing that:

"If you are applying for a mortgage, you should have an income and banks are not allowed to take 30% of that income, the rest must be left for basic things you need. Even if you apply for a government subsidy."

4.3.1.2 Housing Backlog Crisis in South African Society

Across the board, the majority of participants underscore the serious issue of the growing affordable housing backlog in South Africa. A2 emphasises the magnitude of the problem, stating that *"currently, the housing backlog in South Africa is 2.5 million, and this housing backlog is increasing every year."* While acknowledging that this figure is from a few years ago, A2 recognises that the backlog has likely increased even further in the present year. E1 succinctly describes the affordable housing backlog as the core problem faced by South Africa. As highlighted in the literature, this backlog gives rise to severe challenges such as homelessness, crime, and the spread of diseases. Fortunately, the participants highlight a unanimous solution to the backlog, this is with the *"utilisation of innovative technology"* says E1. Further claims from E1 address that the implementation of innovation will be a "positive thing for South Africa". P1 adds that speed is a crucial factor in eradicating the backlog, and the adoption of innovative technology can facilitate faster delivery of houses to meet urgent housing needs.

4.3.2 Theme 2: Affordable Housing Issues and Possible Remedies

This theme explores the challenges faced in developing and delivering affordable housing in South Africa and presents potential remedies to address these issues. Participants identified various factors that contribute to the challenges in the affordable housing sector. The primary challenge highlighted was the cost of land, which limits available funds for the construction of housing structures. A2 emphasises that *"the cost of building materials, the cost of putting up the top structure, it is across the income bands, it's an issue."* Additionally, the availability of land was identified as a major constraint, resulting in poor-quality housing. E3 further argued that inadequate housing provision contributes to overcrowding and homelessness. P1 pointed

out the reduction in fiscal subsidies from the government and the growing demand as significant challenges. The high costs associated with developing affordable housing were also noted, as mentioned by E3 who stated that *"everyone still wants your money."* Another participant highlighted the high cost of finance for end users. However, participants recognised the potential benefits of innovative technologies in addressing these challenges. E1 stressed that the utilisation of innovative technology would be a positive step forward for South Africa. Participants identified various advantages of adopting innovative technologies in affordable housing. These included the development of new skills within communities, cost reduction through alternative technology, faster construction, improved quality, energy efficiency, simplified construction processes, reduced reliance on fuel-based energy, and lower life cycle costs. In addition, participants also acknowledged the disadvantages associated with implementing innovative technologies, such as high implementation costs, minimal social acceptance, limited flexibility in altering designs, and concerns regarding job loss in the construction industry.

4.3.2.1 Challenges in Developing and Delivering Affordable Housing

Participants in the study highlighted the challenges associated with developing and delivering affordable housing, particularly in relation to the costs and availability of land, as well as the costs of building materials.

Costs and Availability of Land:

Participants in the study identified challenges related to the development and delivery of affordable housing, specifically highlighting the costs and availability of land as significant obstacles. As E1 stated, *"The biggest premium is the land and it minimises the top structure".* A2 further supported this point, stating that *"the first challenge is the availability of the land"*. The literature corroborates these findings, underscoring the phenomenon of urbanisation in major South African cities such as Gauteng. P1 recognised the unique nature of urbanisation in Gauteng, stating that it has *"the biggest population in the smallest area geographically*", with this dynamic, P1 also states that:

"The cost of land makes affordable housing and low-income housing not economic".

However, participants are aware of the current dynamic with land in South Africa. E1 states that the biggest issue is that *"there is land in the hands of the government, and premium land that is in the hands of the private sector".* As a result, there will be some land (government-owned) that can be deemed "affordable" for affordable housing development, however, the end user may not consider this government-owned land affordable due to a few factors. E3 best describes this issue of land placement that is affordable for end users stating that:

"the preferred land should be close to amenities; do we have plenty of land in South Africa for that? The answer remains no."

Based on E3's reasoning, affordability for the end user should take into consideration the various factors that may increase the end user's monthly expenditure. This notion is argued by A1 who asks:

"Where do people have to travel from where they live to where they can walk to destinations? When you look at it from a holistic perspective. You can get a good cost-effective house, but if it's somewhere that takes you 40km to travel to work and back. At the end of the day, it's no longer affordable."

Therefore, developers not only face increased development costs but also the challenge of selecting suitable land that minimises additional costs for end users. Unfortunately, viable land options that enable cost-effective development and reduce end-user expenses remain limited.

Heightened Costs of Construction Materials:
Participants in the study not only identified the costs and unavailability of land as significant challenges in affordable housing development but also recognised the cost of materials as a predominant issue. A1 initially highlights that "most of the decisions that we take are at the construction level", as a result, these decisions can have positive or negative effects on the delivered product which includes the cost and quality of the house. Considering this notion, participants highlight that at the construction level, one of the main challenges is the heightened costs of materials, P1 simply states that *"there are problems that we said affordable housing have that are generic, like the cost of building materials",* E3 argues that a large expenditure in affordable housing development is the materials purchased. A1 shed light on the reality by stating that developers:

"focus on looking at and implementing cheap materials, but we don't look at what will be the implications of these materials over the life cycle of the house."

These implications are a direct link towards substandard housing, this is why participants such as A2 highlight that one of the challenges in affordable housing development is the *"quality of the houses that are delivered on the ground".* However, the costs of material will remain a volatile issue, considering the war in Russia and Ukraine, the prices of cement prices suddenly "shoot up by 30% or more". As a result of expensive materials, some developers will use cheap building materials and will:

"try to put up something that looks like somewhat of a structure. We aren't following any single rules of how we should build; this is what is referred to as substandard housing" (P1).

Consequently, some developers resort to using inexpensive building materials, resulting in structures that lack adherence to proper construction guidelines.

4.3.2.2 Benefits of Innovative Technologies in Affordable Housing
During the interviews, participants shared their professional perspectives on the advantages and disadvantages of the various technologies they use. While some highlighted specific advantages and disadvantages of technologies like 3D printing, E2 noted that:

"3D printing is a brilliant technology, it's just that economies of scale and scalability and cost-effectiveness prevent it from being more proliferated."

The advantages and disadvantages of innovative technology adoption were presented as a whole, encompassing technologies such as Object-Oriented Design, BIM, GIS, Smart Sensors, Project Portfolio Management, 3D Laser Scanners, Drones, Modular Construction, and 3D Printing. These advantages have an overarching focus on the potential benefits and drawbacks of each technology. Common advantages of innovative technologies presented by the participants:

Building with Innovative Technologies Leaves New Skills in Communities:
Adoption of these technologies will *"leave new skills in communities, when you build these houses in communities, people will continuously maintain these technologies",* says E1.
Alternative Technology Can Bring Down Costs: P2 states that "*our summaries have shown us that alternative technology can bring down costs."* This is best seen in technologies such as Modular Construction and Prefabrication. Leveraging technologies and pathways like offsite

construction leads to a lot of prefabrication, which is more cost-effective and helps construction companies manage costs well. A2 concludes that:

"the use of innovative building materials can assist in providing alternative methods of construction which are more affordable."

Housing Built with Innovative Technologies is Simpler, Better, Faster, and More Cost Effective:
P2 argues that *"housing built with Innovative Technologies can be built 'simpler, better, faster, and more cost-effectively.'"* Combined usage of BIM for 3D designs, Virtual Reality to experience the design, and the usage of sensors and drones on-site can help monitor the process of construction to ensure the plan is in line with the original designs in BIM. The usage of these innovative technologies is not only affordable but also quicker to construct. Therefore, if they are quick, one can deliver a product at a more affordable cost.

Modular Construction Can Be Energy Efficient in the Long Run:
A2's statement highlights the potential energy efficiency benefits of innovative building technologies such as Modular Construction. According to A2, this technology can help maintain comfortable indoor temperatures throughout the year, keeping houses warm in winter and cool in summer. The use of energy-efficient technologies in the construction of affordable housing can lead to lower energy consumption and cost savings in the long run. This suggests that further exploration and adoption of such technologies could be beneficial for promoting sustainable affordable housing in South Africa.

Smart Sensors and Drones Simplify the Construction Process:
Technologies such as Smart Sensors and Drones make the construction process simpler to monitor real-time data on-site for construction managers as well as future data reading once the housing has been handed over to the new owners:

"Smart sensors will be used in real-life scenarios and let an owner lives in this house" (P1).

Such monitoring technology can even be useful in avoiding material theft, as well as helping with logistics on site. *"It lets you know when your rental or cement is on its way. It's the automation of the process,"* says A1.

Reducing Reliance on Fuel-Based Energy:
E3's statement highlights the potential of innovative technologies to reduce the reliance on fuel-based energy sources in the construction industry. According to E3, traditional building materials are known to emit heavy energy, and adopting innovative technologies can bring about a positive change in this regard. The use of innovative technologies can lead to the development of more energy-efficient and sustainable building materials and processes, thereby reducing the environmental impact of the construction industry. E3's perspective highlights the potential benefits of adopting innovative technologies in the construction industry, not just in terms of cost and efficiency, but also in terms of sustainability and environmental impact.

Faster Building and Low Reliance on Natural Resources:
E2 identifies that their Alternative Building Technology, a structurally insulated panel using SIP technology, is eight times faster than conventional building systems and has a low reliance on natural resources such as water, sand, stones, and cement.

Higher Quality Housing with Innovative Technologies:
The usage of offsite manufacturing with factory-produced assets can result in higher quality products and avoid challenges such as incorrect concrete mixtures or worker accidents. A1 notes that:

"Slabs on the walls remove most of those risks that you may have that could delay projects. So, it helps with efficiency and quality."

The controlled environments provided by innovative technologies result in better results and A2 addresses that:

"The method of assembling the products is much better than your conventional brick-and-mortar."

Lower Life Cycle Costs with Innovative Technologies:
Although the initial costs of implementing innovative technology can be high, a participant highlights that the life-cycle costs are less. Additionally, A2 highlights that:

"Innovative building technologies offer a better life cycle cost than your conventional brick and mortar. You might be able to utilise waste materials more effectively, reduce waste on-site, reduce time to deliver the product, reduce energy consumption, and emit fewer carbon emissions."

4.3.2.3 Perceived disadvantages of innovative technologies in affordable housing projects

Despite some potential benefits, participants identified several challenges and drawbacks associated with implementing these technologies in affordable housing development. Table 4.3, code T2, outlines the specific disadvantages that were identified, including:

Costs of Implementation:
The initial costs of implementing innovative technology can be high. E1 notes that although costs can vary depending on the technology, there is a substantial amount that a company would need to pay compared to using traditional methods, which aren't as costly. E1 also mentions that bigger companies tend to adopt innovative technology more due to their financial capacity. However, emerging contractors face challenges. In some cases, these contractors would acquire the technology for a project and worry that they use it only once. Similarly, E1 explains:

"If something in the house isn't good, I can get Joe Soap to come and fix it. Then if you use innovative technologies, if something goes wrong, you'd have to get specialised professionals to come and fix which would cost the homeowner an arm and a leg."

Additionally, maintenance and upkeep of innovative technology can be costly as few experts deal with it. Innovative technology experts are around in smaller numbers compared to experts in the brick-and-mortar sphere of construction. Further, there is an increasing demand for expert assistance, which causes prices for these experts to rise. E3 concludes this point by stating:

"In most cases, that person is the supplier, in terms of the professionals in this field, there is a limited scope. That won't bring the cost down, thus the expensive nature of IBTs."

When focusing on specific technologies with limited supply in South Africa, such as 3D Printing, materials will need to be shipped over, hence the heightened costs of materials for some of these technologies.

Minimal Social Acceptance:
The current social acceptance of innovative technology within South Africa amongst households in need of affordable housing is the second most highlighted theme. Many people in the South African affordable housing market believe that 3D printing and modular construction, two innovative technologies, are inferior to traditional brick-and-mortar houses. As A2 noted:

"The knock-on effect – if I knock on the wall and hear a knock-on sound, I have the perception that this a poor-quality material and therefore, as a beneficiary or end-user, I am not interested in that technology because of the perception that it might be a poor-quality material."

P1 identified that *"To those that don't know these technologies, it doesn't make sense."* People are used to brick and mortar and E1 indicates that: *"it is something that they know and would rather bet on that."* Participants with a government background identified a different perspective of social acceptance. If such technologies are presented to the government and could provide long-term benefits at a heightened initial cost, the government would prefer the option that solves the issue today rather than tomorrow. As P1 stated:

"In the built environment… if you did something spectacular, like build a house that floats in floods. It will cost you about R1 Billion to just do one product. So, the government will say… Why don't you just build for half a million people, then we know half a million people have shelter as opposed to this one house that's floating when it floods.'"

The government needs to see a live demonstration to be convinced of its effectiveness. In addition, P1 states that:

"When you look at a smart brick, you need to do at least 100 or 1000 to do a demonstration. If you do a demonstration of your smart brick, you need at least 10,000, so how much would that cost you? It then becomes costly to demonstrate even. The government will just say let's use normal housing and give many poor people shelter."

Inability to have the flexibility to alter designs in the future:
The third most addressed disadvantage is the future ability to alter the produced house. In traditional housing, one can simply go to their local building shop to get materials to fix any small issues. However, this becomes a problem when the house is modularly constructed or built with 3D printers. As A2 noted that people need to be adequately trained to understand these technologies so that they can be implemented correctly and avoid future problems for end users. Nevertheless, end users will have limited ability to rectify any issues that may arise due to their insufficient knowledge of the technology. As a result, the price of experts in this field is heightened.

The heightened fear of Job Loss:
At an economic scale, a disadvantage could be the initial loss of jobs within the construction industry. As technology becomes more capable, it replaces human labour by performing tasks faster than humans. This can result in a decrease in jobs, although it is helpful. P2 notes that:

"We need to be creative and innovative in terms of how we can trade off building houses more quickly and efficiently without shedding too many workers."

4.3.3 Theme 3: Innovative Technology Adoption in South Africa

4.3.3.1 The Role of Innovative Technologies in the Participants' Practices

When it comes to new technologies, the lack of knowledge transfer is a common cause of delays in affordable housing development, according to one of the themes that emerged from the interviews. To address this, professionals were asked to identify the technologies they use to aid in the development of affordable housing. While some participants were policymakers and academics, the majority of the professionals interviewed used modular construction. However, A1 notes that although modular construction is gaining popularity, it is mostly being used for upper-class housing and in developed nations. Other technologies employed by participants include BIM, GIS, drones for inspection, Object Oriented Design, and Project Portfolio Management. E2 solely uses innovative building technologies, such as structurally insulated panel (SIP) technology, which is the fastest-growing alternative building technology in the world, as well as PBC windows, PBC ceilings, and solar-linked LED lights with batteries. Additionally, A2 notes that they use 3D technology to a limited extent, stating that:

"it is still a new technology, and it has not yet matured to a level people expect it to be used daily."

4.3.3.2 Innovative Technology Adoption in South Africa

Once discovering the various advantages and disadvantages of these technologies, the participants highlighted the current status at which these technologies are being implemented within the South African affordable housing sector. All participants agreed that these technologies are not yet fully utilised in the current South African affordable housing market. According to P2, the government plays a vital role in promoting the adoption of innovative technologies among practising companies, both private and public. E1 suggested that the government should provide incentives to utilise the technologies. Such incentive programs can be in the form of grants, and companies would not hesitate to use the technology in these circumstances. However, the government needs to be more proactive and begin showcasing, embracing and promoting alternative building technologies, or there will be limited adoption. E3 said that: *"the SA government talks about Innovative Technologies, but no action follows that."* The participants identified social perspective as a significant factor in increasing the usage of these technologies. The market may be ready, but no one wants to take the lead. This makes potential suppliers reluctant and causes them to invest in other ventures. E2 identified fear of change as the reason, *"they do not want innovation; they want things to stay the same."* This reluctance to change is a problem that inhibits innovation. P2 commented that *"We want to stick to the safe and narrow. Which is a problem."* Participants such as A1 and A2 agreed that technology is used in less than 5% of projects, even though the government has put in place policies and initiatives to promote the use of innovative building technologies, such a figure is similarly stated in this study's online surveys with home developers which indicates a low level of adoption of innovative technology. P1 noted that the usage varies from province to province, and provinces such as Gauteng, the Western Cape, and KwaZulu-Natal are more on the forefront with technology usage than the Northern Cape. A1 also pointed out that when used, innovative technology adoption is mostly geared toward commercial buildings or high-net-worth individuals, *"where there is an increased appetite for technology-driven and innovatively driven houses."* The nation still has a long way to go before adopting innovative solutions. However, regardless of the technology involved, one participant highlighted that it took Switzerland approximately 100 years to *"master social housing."* South Africa does not need to spend that long, but if technology can be adopted at a faster rate, the country can master

social housing faster than Switzerland did. In addition, seven years ago, the government set a quota of 60% of all social infrastructure projects that should be built using innovative technologies. Five years later, less than 5% was done using innovative technologies. A2 concluded that:

"The uptake is not happening. The reason for these leverages comes back to the previous question of the disadvantages, which talks more about the perceptions of people, particularly in housing."

Therefore, stronger investment from the government and a change in perspective around the notion of innovative technology is needed. A2 concluded:

"It is a perception issue that we need to deal with. Overseas, innovative building technologies are being used. They don't even call them innovative building technologies because it is their conventional. In North America and some parts of Europe, they build using timber. But a timber house would not be accepted in South Africa because we have a feeling that brick and mortar is the best. So, the uptake is not that good."

4.3.3.3 Social Acceptance of Innovative Technology

In the participants' expert opinions, they all have realised that social acceptance remains a prevailing theme within the South African affordable housing sector that limits further investment from companies and end users. Innovative technologies, especially technologies such as 3D Printing, Modular Construction and various IBTs, can drastically improve the rate of houses delivered and quality. However, even with all these advantages, E1 notes that:

"Most housing consumers reject it on the spot, because they are so used to the brick and mortar, and then they come and find that the wall is hollow".

The usage of brick-and-mortar building methods is familiar and reliable to the eyes of the housing consumer. *"People have perceptions that these technologies are inferior to brick and mortar"*, states A2, hence the fear of its further adoption. The common cause for this is the current framing of Innovative Technologies within South Africa. Best articulated by E3 who states that *"In South Africa, Innovative Technologies are intended for the poor. In Western countries, Innovative Technologies are often used by rich people."* Participants strongly urge the government to enforce the usage of Innovative Technologies more in upper-market housing to demonstrate that it is not a technology *"for the poor".* For example, E1 argues that:

"You need to incentives the market to have an uptake of it, people need to be exposed to seeing it. Like, showing people how it could be used in areas of Sandton and showing that normal people can utilise the technology. Then from there move it towards low-cost developments."

Thus, A1 strongly indicates that when building the affordable housing market, it should not be done in a manner that points out that it is an affordable housing scheme, developers must ensure it blends with other houses in different markets, *"this makes it easier for people to make it mainstream into society by making them not look like shacks or people that can't afford much."* The importance of this issue has been summarised by P2 who stated:

"The issue is poor people want exactly what everyone else wants. If you want to drink Coke, don't drink Coke, and then tell poor people to drink Pepsi."

If the lower-market end users see something is consumed by other people, it will be something that they then inspire to have themselves. Ultimately, housing professionals must have a social acceptance component embedded into their systems and policies. P2 did a social acceptance survey and people knocked on the external wall of the modular constructed house, they found:

"it sounded like the shack back home, they frowned upon it, and simply would not buy into the idea of living in that house. They say it is just another shack – it is out of their concern."

Similarly, not only is social acceptance from the end user important, but the social acceptance from the investors also plays a vital role, hence the importance to receive buy-in from the government to enforce the usage of the technologies and from the developers who will then use the technology, P2 simply states *"There are some wonderful systems out there that can go to market very quickly, they just need government and investor support."*

4.3.3.4 Challenges and Barriers to the Adoption of Innovative Technology in the South African Context

The participants acknowledged that while social acceptance is the main challenge to the adoption of innovative technologies in the affordable housing sector, other barriers also need to be addressed.

Maintenance:
Based on the findings from E1, it was revealed that the limited supply of maintenance experts for innovative construction technologies leads to increased maintenance costs. E1 highlighted that this is a persistent issue that has a direct impact on the overall affordability of housing. The high costs of maintenance not only affect the affordability of housing for prospective homeowners but also for current homeowners who may struggle to keep up with maintenance costs. E1 further noted that the heightened maintenance of these technologies remains evident, and the costs of maintenance increase substantially. These findings underscore the importance of considering the long-term costs and maintenance requirements of innovative construction technologies when evaluating their suitability for use in the affordable housing sector. This highlights the need for a holistic approach that considers not only the initial costs of implementing these technologies but also the costs associated with their long-term maintenance and operation.

Limited Capital for Innovation:
P1's suggestion highlights the need for increased investment in innovative construction technologies by construction companies and governments, with a comparison drawn to Apple's approach to investing in new product innovation. While such investment can lead to improved efficiency, affordability, and quality in the construction industry, P1 also acknowledges the potential barriers to such investment, particularly in terms of cost. The statement suggests that there may be a perception that the cost of investing in innovative construction technologies cannot be justified, potentially hindering progress in the adoption and implementation of these technologies. This highlights the importance of considering the costs and benefits of such investments and identifying ways to make them more viable and appealing to construction companies and governments.

Lack of Knowledge Transfer:
Participants identified a lack of knowledge transfer as a barrier to the adoption of innovative technologies in the affordable housing sector. According to E3:

"There are limited universities that provide intensive curriculums teaching students the full extent of innovative technologies such as 3D Printing, Modular Construction, Virtual Reality, Artificial Intelligence, and many more."

E3 further states that universities typically only introduce these innovative technologies during the postgraduate stage as add-ons, rather than as key solutions that can revolutionise the South

African housing development market. As a result of this limited exposure, there is also a lack of knowledge about innovative technologies among professionals currently working in the field. As the same A2 explained:

"if the professional does not understand innovative building technology, who will tell the consumer or end user that you can use this technology? The professional should be able to tell them of alternatives to the conventional brick and mortar… if the contractor is not trained adequately, they will stick to the brick and mortar to not spoil their reputation."

A2 suggested that students in the tertiary education system should be exposed to various types of innovative technologies so that they can be the ones to suggest innovative technologies when they start working for contractors or professional consulting companies. By providing more intensive curriculums that cover innovative technologies in greater depth, universities can help to ensure that the next generation of professionals is equipped with the knowledge and skills they need to support the adoption of innovative technologies in the affordable housing sector.

Cultural Resistance to Change:
Resistance to change is a major challenge facing the adoption of innovative construction technologies. Some professionals believe that these technologies could disrupt their jobs and workflow, leading to reluctance to adopt them.

Lack of Regulation:
Innovative construction technologies have minimal regulatory status, which means that there is no legal risk for developers who choose not to implement them. However, as A1 notes, *"You may think you become successful, but you're not"* in the long run.

4.3.4 Theme 4: Impact of Innovative Technology on Affordable Housing Delivery

This theme explores the impact of innovative technology on the delivery and cost of affordable housing in South Africa. Participants in the study identified various factors that contribute to delays and cost overruns in affordable housing projects. Excessive bureaucracy, municipal and regulatory red tape, improper planning, lack of skilled labour, limited availability of quality materials, and the industry's reliance on labour were among the challenges mentioned. However, participants also acknowledged that factors beyond their control, such as the economic climate or unexpected events like the COVID-19 pandemic, can cause delays. In addition, participants recognised the urgent need for faster construction methods to address the housing backlog in South Africa, which has reached approximately 3 million houses. Participants highlighted the potential of innovative technologies to significantly improve the speed of construction. Despite the positive attributes of innovative technologies, participants identified certain conditions that must be met for its success, these included effective marketing and communication, social acceptance facilitated by the government, and a willingness among individuals to embrace the technology even if it impacts job security. Participants also discussed the impact of innovative technology on the costs and affordability of affordable housing. They believed that innovative technology has the potential to reduce costs and improve affordability in the long run. While initial adoption costs may be high, participants predicted that increased awareness and wider adoption would lead to further cost minimisation.

4.3.4.1 Factors Contributing to Delays and Cost Overruns in Affordable Housing Development

Participants in the study identified the causes of delays and cost overruns in affordable housing in a few key points, these include excessive bureaucracy, uncontrolled parameters, improper planning, lack of skilled labour, and limited availability of quality materials.

Excessive Bureaucracy:
The participants immediately identify "red tape" as one of the main hindrances causing delays and cost overruns in affordable housing development. Essentially, red tape alludes to excessive bureaucracy at the municipality or government level. P1 states that "At some point I checked and there are over 200 steps involved to get a full township *established and it would take up to 3 years to finish." Similarly,* E2 agrees and highlights that this excessive bureaucracy is *"red tape that is regulatory orientated and delays from either the main contractor or the municipality regarding the installation of civil infrastructure."*

The issue with red tape is that not only does it lead to delays in delivery, but these delays lead to costs that accumulate. For example, P1 addresses that for a project to take 3 years to complete, various problems may arise, P1 states *"If you are doing cost projection, cement prices increase 6 times in one year. Imagine how outdated and irrelevant your cost projections are going to be. We don't have quick processes."* P1 concludes by arguing that there has to be a faster process. A2 addresses that *"Some of the cost overalls are possibly due to the long delays in the project".* For households applying for affordable housing according to the FLISP market, there already are "approval delays" says P1, causing households to wait extended periods for their application to be approved and waiting prolonged periods for their house to be developed and delivered. South Africa needs to migrate towards the digitalisation of tasks, from basic to complex. P1 highlights that:

"If you look at New Zealand, when you are doing a deeds registration, within 24 hours your house is registered, it's done electronically. We are still going physically to a deeds office and it's still taking several weeks. We must up our game and join the tech world and go online. Time is money, especially in housing."

Uncontrolled Parameters:
Participants acknowledge that although there are parameters that are in their control, there are other forces at play that cannot be controlled which directly affect the delivery time or costs of affordable housing projects. From a policymaker's perspective, P2 highlights that the municipality had a 5-year plan for construction but events such as the COVID-19 pandemic had a serious toll on the nation. P2 notes that:

"Our biggest hindrance is caused by having 5 years plan, and then all construction had to stop due to the COVID-19 pandemic."

This simply addresses the fact that contractors can prepare to build at scale, procurement systems can be put in place, concrete plans are in order, and all can be approved by the government, but economic factors or unexpected plans can negatively affect the delivery rate of affordable housing.

Improper Planning, Lack of Skilled Labour, And Limited Availability of Quality Materials:
Participants also noted the issue of improper planning, lack of skilled labour, and limited availability of quality materials. A2 explained, *"There is a huge shortage of materials or affordable materials. The materials are very expensive. One needs to investigate alternative ways of having materials for building construction."* This factor plays into the improper planning which is clear in the South African affordable housing industry. A2 further explains *"Contractors would put a lot of costs into the foundation so at the end of the day the costs are much higher than what was budgeted for."* As a result, these contractors will cut corners and use cheap materials resulting in substandard housing being built. A1 agrees with this and argues that:

"There is a tendency for stakeholders to not have the success criteria of timely delivery or minimised costs. It's more about eventually delivering that house or just reducing the backlog that prevails over the economy. Because of that, everything suffers. With untimely delivery, poor decisions contribute to overall delays."

The participants address that the underlying issue is directly linked to unskilled professionals. A1 argues that "we need to end up training people in those communities." A1 identifies that the South African construction industry is still "labour-intensive" because construction still remains an outdoor activity, A1 identifies that:

"We are submitted to things like inclement weather, were submitted to things like diseases or infections, which leads to a demoralised workforce that doesn't have the motivation to put in 100% every time."

As a result, there must be intentional efforts to train professionals to handle the current issues that face the South African construction industry, however, "until that's done there will be a lot of rework in construction, which leads to cost overruns" claims A1.

4.3.4.2 The impact of Innovative Technologies on the cost and delivery of Affordable Housing.

Affordable housing delivery and affordability were the main topics of discussion among the participants. In terms of housing delivery, the participants acknowledged the current housing backlog in South Africa, with A2 pointing out that it has increased to around 3 million houses. This has made the need for faster construction methods all the more pressing. A2 further suggested that innovative technologies would be the key to addressing this issue, stating, *"Only innovative building technologies can provide a high speed of construction."* A2 thereafter emphasises the importance of modular construction, stating that *"with modular construction, you can put maybe 3 panels in a few minutes, clip them, and you are done with the wall."* P2 argued that:

"with alternative building technology, if there is a new need for 1000 households a day, we are going to deliver 1500 houses a day. So, we are going to cover the emerging need and we are going to cover the backlog."

Despite these positive assessments of innovative technology, the participants also recognised the need for certain conditions to be met to ensure its success. P1 stressed the importance of using the technology at scale to test its overall effectiveness, while another participant argued that the technology should be marketed and communicated effectively. Additionally, the government must take the lead and ensure that the technology is socially accepted. A1 simply stated that *"people should want it to commence at the expense of their job."*

In terms of the impact of innovative technology on the costs and affordability of affordable housing, the majority of participants believe innovative technology will eventually reduce costs and improve the affordability of affordable housing. This is an important consideration as P2 argues that *"affordable housing is housing that is not affordable",* thus, finding remedies to minimise the costs of development will seemingly aid in decreasing the high costs of affordable housing. Although initial adoption costs are currently high for most innovative technologies due to limited supply, participants predict that as more users buy into the technology, market forces will achieve equilibrium and costs will become more affordable. As A1 notes, *"The more buy-in over time, the lower the initial costs."* For example, the first cell phone brought into South Africa was expensive, but now there are various phones available at affordable to expensive prices. However, initial buy-in is critical for wider adoption, otherwise, the

technology may only be preserved for the rich. Regarding the role of the government in the adoption of innovative technologies, E3 suggests that "50% of the budget (currently more than R33 billion per year) for affordable housing could be used to purchase innovative building technologies, which would push IBTs and bring awareness to the market." Increased awareness of the benefits of innovative technology would result in reduced initial adoption costs. Additionally, participants suggest that in the long run, innovative technology will lead to cost minimisation. E1 argues that *"it will ultimately have a positive impact on the costs within the country. The consumption of our energy will decrease as well with energy costs."*
However, it is important to note that maintenance costs should be considered for these affordable houses. P1 states that:

"if you install smart bricks, modular construction or smart sensors, users will need to maintain those sensors. A specialised expert must go out and check that it still fits, that they are well placed and it still gets the data it was put there for."

The costs of maintenance for innovative technology will be substantially higher than that of traditional brick-and-mortar technology. Similarly, P1 also points out that while a homeowner with sufficient income may be able to afford to install solar units and pay for maintenance, those in lower-income brackets may struggle to pay for these additional costs. Therefore, policies need to be put in place to ensure the effective affordability of housing for end users. For instance, the participant suggests that if an end user takes a house with innovative technology, they must earn a certain income and be able to pay for maintenance costs, such as R10,000/year or R5000/year. Ultimately, the costs will decrease in the long run with more buy-in from stakeholders and investors, but certain prerequisites must be considered to ensure the effective affordability of housing for end users.

4.4 Discussion of Findings:

The previous sections have presented the results of the data analysis, providing insight into the perceptions, experiences, and challenges related to the adoption of innovative technologies in South African affordable housing projects. In this section, the findings will be synthesised and discussed in light of the research questions and the existing literature. The discussion will explore the implications of the study for theory, practice, and policy, as well as the limitations of the research and the directions for future research. By engaging with the findings and their meaning, this section aims to contribute to a deeper understanding of the opportunities and obstacles for using innovative technologies in the affordable housing sector and to offer recommendations for enhancing their effectiveness.

4.4.1 Innovative Technology has a high impact on the Affordability of Affordable Housing

Despite some concerns raised in the research findings, the overwhelming evidence supports the positive impact of implementing innovative technologies in affordable housing construction, particularly in terms of cost and delivery. Table 4.3 summarises the impacts of each technology, it uses previous RII calculations as a basis for coming to the outcome. This table obtained the level of impact from the RII calculation. RII values higher than 75% were categorised as “Very High Impact” while values between 65% and 75% were categorised as “High Impact”. Ultimately, this table highlights that most of the participants argue that these technologies will have a very high impact on the affordability of affordable housing developments. The top three technologies, Project Portfolio Management, Modular Construction and BIM should be considered in many South African affordable housing projects.

Table 4.3 Impacts of Innovative Technologies on Delivery and Affordability of Affordable Housing in South Africa

Innovative Technology Impacts on Delivery of Affordable Housing		Innovative Technology Impacts on Affordability of Affordable Housing	
Technology	**Impact**	**Technology**	**Impact**
PPM	Very High Impact	**PPM**	Very High Impact
Modular Construction	Very High Impact	**Modular Construction**	Very High Impact
BIM	Very High Impact	**BIM**	Very High Impact
GIS	Very High Impact	**GIS**	Very High Impact
Smart Sensors	Very High Impact	**Smart Sensors**	High Impact
3D Laser Scanners	Very High Impact	**3D Laser Scanners**	High Impact
Drones	Very High Impact	**Drones**	High Impact
3D Printers	Very High Impact	**3D Printers**	High Impact
OOP	High Impact	**OOP**	High Impact

Literature highlights that one of the major advantages of these technologies is the potential for long-term cost savings through improved energy efficiency and construction efficiency. For instance, modular construction has been shown to reduce construction time by 50% and cost by 20% (McKinsey, 2019), while 3D printers can significantly decrease construction time and improve efficiency by reducing the time required to construct building components compared to conventional systems (Leal, et al., 2017; Buswell, et al., 2007). Moreover, these technologies can support the entire supply chain process by ensuring efficiency in design, minimising errors, and reducing the risk of potential rework during the construction process, this is clearly seen with technologies such as Project Portfolio Management and BIM. The faster a construction project is completed, the lower the overall costs, according to scholars (Buswell, et al., 2007). Overall, the research strongly supports the potential benefits of innovative technologies in affordable housing construction.

4.4.2 Innovative Technology Has a High Impact on the Delivery of Affordable Housing

Similarly, the research findings support the notion that innovative technologies can lead to cost savings and faster construction processes in the affordable housing sector. In addition, participants believe that these technologies can significantly improve the delivery rate of affordable housing. Table 4.3 addresses the participant's views by summarising that the majority of the surveyed home developers believe innovative technology will positively impact the delivery of affordable housing projects. Similarly, in ranking, participants lean towards Project Management, Modular Construction, GIS, and BIM as technologies that have the highest impact. These findings coincide with the literature, for instance, modular construction provides a faster delivery solution at lower development costs, making it beneficial for the affordable housing sector (Thomson, 2019). 3D printing systems are also known for their increased speed in construction processes. Moreover, innovative technologies used during the design process can improve collaboration between stakeholders, communication, visualisation, and clash detection (Farnsworth, et al., 2015). Smart sensors can also alert site managers about the next phase of the construction process (Nichols, 2020), while VR technology can help designers view construction designs at a 1:1 scale (Brooks, 2022), improving accuracy in decision-making and speeding up the process. Technologies such as Augmented Reality, Portfolio Project Management, Object-Oriented Programming, UAVs, Artificial Intelligence, and GIS can also improve the design process, monitoring, and clash detection, ultimately leading to faster and more efficient delivery of affordable houses. These benefits have been demonstrated in various real-world applications and suggest that the use of innovative

technologies has the potential to significantly improve the affordability and accessibility of housing in South Africa.

4.4.3 Innovative Technology Adoption Sparks New Skills, Decreased Costs, Improved Quality and Faster Delivery Times

The research findings emphasise that innovative technologies can offer numerous benefits to the construction of affordable housing in South Africa. These benefits include the potential for new skills to be developed in local communities, lower costs of construction, energy efficiency, and higher quality housing. The research findings indicate that modular construction, smart sensors, and drones are examples of technologies that can simplify the construction process, causing it to increase productivity and efficiency. Such is best represented in literature, where researchers argue that modular construction is expected to bring about several benefits, including cost reduction, improved construction delivery time, and enhanced building quality through better energy consumption (Bertram, et al., 2019). Furthermore, smart sensors are most effective in optimising project efficiency and monitoring by enabling visibility of data, tracking of assets, and proactive maintenance of machines (Nichols, 2020). Drones have the potential to drive digitalisation in the construction industry, by supporting various tasks such as building surveys, topographic mapping, land surveys, construction site inspections, equipment tracking and automation, remote monitoring and progress reporting, laser scanning and aerial photogrammetry, and thermal imaging recording (Tkáč & Mésároš, 2019).

4.4.4 There Are High Costs Involved in Innovative Technology Adoption, Maintenance and Operation

However, there are also potential disadvantages to using innovative technologies in affordable housing construction in South Africa. In addition, the research findings strongly identify that these technologies tend to obtain a high adoption cost, making it expensive for construction companies to implement them in their practices. This is seen in earlier findings represented in Table 4.1, showing that the cost of adoption is one of the highest recorded challenges towards innovative technology adoption in the construction industry. The findings highlight that one major concern is the high cost of implementation, which could make it difficult for low-income families to afford these homes or for smaller companies to adopt these technologies. Likewise, the literature indicates a significant economic burden associated with the adoption of innovative technology, particularly for early investors (Buchanan & Gardner, 2019). The initial costs of introducing newer technologies are often prohibitively high due to the substantial capital outlay, making it challenging for early adopters (Mahachi, 2021). This cost can be broken down into three categories: initial costs, maintenance costs, and operational costs. Thus, researchers will indicate clearly that technologies new to the construction industry, including AR, VR, 3D Printing, and AI, will have a higher cost of adoption due to the immaturity of the technology (Heinzel, et al., 2017).

4.4.5 Limited Adoption of Technologies Hinders Affordable Housing Delivery in The SA Construction Industry

In the combat of these issues stemming from South Africa's construction industry's slow reaction towards affordable housing demand, further findings identify that the majority of participants believe that innovative technologies have the potential to address these challenges and improve the affordability of housing as well as the delivery rate. In support of this finding, it is clear in the literature that the implementation of digitalisation in the housing supply chain can potentially facilitate continuous workflow improvement in the manufacturing process, leading to the elimination of rework (Shahparvari, et al., 2019). Various scholars strongly claim

that around the world, the construction industry generally possesses a cultural resistance to change, causing limited innovation within the industry (Shahparvari, et al., 2019).

Table 4.4 Familiarity, and Usage of Innovative Technologies in Affordable Housing Design and Construction

Familiarity of Innovative Technologies		**Level of Usage of Innovative Technology**	
Technology	**Interpretation**	**Technology**	**Interpretation**
PPM	*High familiarity*	**PPM**	*Very Low level of usage*
BIM	*Moderate level of familiarity*	**Modular Construction**	*Very Low level of usage*
GIS	*Moderate level of familiarity*	**GIS**	*Relatively low level of usage*
Modular Construction	*Moderate level of familiarity*	**BIM**	*Relatively low level of usage*
Drones	*Moderate level of familiarity*	**Drones**	*Very Low level of usage*
3D Printers	*Moderate to low familiarity*	**OOP**	*Very Low level of usage*
OOP	*Moderate to low familiarity*	**3D Laser Scanners**	*Very Low level of usage*
3D Laser Scanners	*Moderate to low familiarity*	**Smart Sensors**	*Very Low level of usage*
Smart Sensors	*Moderate to low familiarity*	**3D Printers**	*Very Low level of usage*

Innovative yet practical technologies have been introduced within the construction industry, yet Table 4.4 identifies that the majority of the surveyed company representatives expressed a low to moderate level of familiarity and understanding with various innovative technologies and extremely low usage of these technologies, such as BIM, GIS, smart sensors, 3D laser scanners, drones, modular construction, 3D printing, object-oriented programming, and project portfolio management. South African home developers having little to no awareness or understanding of these innovative technologies strengthens the argument that the South African construction industry does underperform due to limited technological adoption. Similarly, Table 4.4 strongly identifies that these technologies exert minimal usage from the affordable housing company representatives. The table shows that the majority of these participants have very low usage of the technologies in their practices, with technologies such as Object-Oriented Programming, 3D Laser Scanners, Smart Sensors, and 3D Printers being the least used technologies respectively. Shockingly, even technologies with high levels of familiarity, such as BIM and GIS, have a very low level of usage as identified by the survey participants. This strengthens the argument that the South African Construction Industry lacks innovation. As a result, this study's literature identified that without adequate technology adoption, the industry will struggle to successfully address barriers that impact the successful delivery of affordable housing (Bennett, et al., 2019; Moghayedi, et al., 2021).

4.4.6 Challenges in Adopting Innovative Technologies in Affordable Housing

The adoption of innovative technologies in affordable housing projects is hindered by a lack of social acceptance, as many individuals continue to prefer traditional building methods. This finding reveals a significant challenge, as it limits buy-in from investors, stakeholders, and end-

users. It underscores the critical role of social acceptance in the successful implementation of innovative technologies in affordable housing. Scholars have identified this challenge as the most significant barrier faced by beneficiaries when delivering a product, particularly with 3D printers, which have already raised concerns among workers regarding their future job security (Richardson, 2017) and potential deviations from conventional home designs (Mahachi, 2021).

The lack of regulations and standards from the government was identified as another crucial challenge. Participants also noted that without government support, there would be no further implementation of these systems. Hence, experts suggest that innovative technologies should be enforced at a legislative level to ensure their adoption in affordable housing projects, as strongly advocated by various experts in literature such as Wortmann et al. (2016). However, until there is a serious increase in social acceptance at the government level, the nation will suffer from a lack of enforcement.

Although various issues stem from limited innovation, minimal government involvement or slow processes from the government play a major role in affordable housing inefficiencies. According to the findings, "red tape" has been identified as a significant contributing factor. In this context, "red tape" refers to excessive bureaucracy or regulations enforced by the government that may impede progress and decision-making. This may entail complex paperwork, redundant procedures, or stringent compliance mandates, which can pose challenges for home development companies to achieve their objectives expeditiously. Literature also identifies that not only does “red tape” slow down the delivery process but there is also minimal enforcement of these technologies from a legislative level (Wortmann, et al., 2016). Such evidence strengthens the reasoning for minimal technology adoption within South Africa’s construction industry, as there are minimal government regulations enforcing the implementation of innovation within standard practices.

When a nation has minimal technology enforcement, there will be minimal awareness of the technology. Hence, the findings identify that the lack of technical knowledge and awareness of innovative technologies was identified as a significant challenge. Furthermore, the wider socio-economic situation in South Africa was recognised as a hindrance to the implementation of innovative technologies and the acquisition of skills and knowledge transfer. This argument is supported by the literature, which suggests that the challenge in countries such as South Africa lies in the constraints associated with education, skills, and knowledge transfer, in addition to the growing complexity of learning newer technologies ('Utoikamanu, 2018). Another important perspective presented by experts is the need to develop innovative technologies not only for affordable housing but also for upper-market houses. This approach can help improve the social acceptance of these technologies, as low-income homeowners can have the peace of mind that their houses are built with the same innovative building technologies as middle to upper-class households. However, the lack of technical knowledge among stakeholders and investors is also a significant challenge to the adoption of innovative technologies. Such claims are best presented by Heinzel et al. (2017), who stated that the underlying challenges towards technology adoption are caused by limited standardisation of these technologies, as well as the lack of familiarity and certainty among end-users and stakeholders, in addition to the increased costs. The literature also identifies that with the lack of skills and increased maintenance costs, these technologies will have less adoption in construction companies (Viljakainen, 2020).

Although these technologies have the potential to improve the overall efficiency of affordable housing projects, it is important to ensure that they are affordable and socially accepted. Additionally, policies should be implemented to address concerns regarding potential job losses and to ensure that local communities can benefit from the development of new skills. Ultimately, the successful implementation of innovative technologies in affordable housing

construction will require a careful balance between these factors. Respondents suggest that until these challenges are addressed, including the high cost of adoption, poor social acceptance, and low technological knowledge, there will be a hindrance to the full adoption of innovative technology within the affordable housing sector.

4.4.7 Summary of the chapter

The study's findings suggest that utilising innovative technologies such as modular construction, smart sensors, and drones in the construction of affordable housing in South Africa offers numerous advantages such as increased efficiency, sustainability, and decreased costs. However, challenges such as high initial, maintenance, and operational costs, lack of technical knowledge, and social acceptance of these technologies need to be addressed. To overcome these challenges, the government can enforce the adoption of innovative technologies through legislative means, increase awareness about their benefits among stakeholders and investors, and provide support to low-income families in need of affordable housing solutions. Overall, with careful planning and support, innovative technologies can be leveraged to provide much-needed housing solutions for low-income families in South Africa.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The affordable housing sector in South Africa grapples with challenges related to delivery and affordability, which contribute to substandard living conditions for migrating households. To address these issues, the adoption of innovative technologies has been considered as a potential solution. This section provides a comprehensive overview of the research, including the aims, objectives, and hypotheses. While the literature suggests that innovative technologies can improve delivery and reduce costs, the survey findings indicate that the impact of these technologies on affordable housing is not as significant as initially expected. However, the research also reveals valuable insights for stakeholders to address challenges such as adoption costs, limited technical knowledge, and social acceptance. By implementing these solutions, stakeholders can further integrate innovative technologies into their practices and enhance the delivery and affordability of affordable housing in South Africa.

5.2 Revisiting the research aim:

The aim of this study was to explore how innovative technologies can impact the delivery process and affordability of affordable housing in South Africa. To achieve this aim, the study adopted a multi-faceted approach. Firstly, a thorough literature review was conducted, which included a comprehensive analysis of various publications and sources that focused on the South African affordable housing market. The aim was to gain a deep understanding of the challenges faced by the market and explore the potential remedies to address these challenges using innovative technologies. Secondly, the study conducted surveys and interviews with relevant stakeholders such as home development companies, their representatives, and affordable housing experts. This allowed for a comprehensive investigation of the current state of affordable housing development in South Africa, including the adoption of innovative technologies, the challenges faced by developers, and the potential benefits that could be realised through the implementation of these technologies. By employing this methodology, the study was able to gather a wealth of data and insights, which allowed for a detailed examination of the research aim. Specifically, the findings revealed that innovative technologies have the potential to significantly impact the affordability and delivery process of affordable housing in South Africa. For example, modular construction and 3D printing were identified as technologies that could reduce construction time and costs, while BIM and Smart Sensors were seen to improve collaboration, communication, and clash detection during the design phase.

5.3 Restating the Research Objectives

Upon gathering and analysing the necessary information, this study successfully addressed each of its six research objectives. These objectives were carefully crafted to gain a comprehensive understanding of the issues facing the delivery of affordable housing, identify the innovative technologies that could potentially address these issues, assess the current level of technology adoption, identify the challenges faced in implementing these technologies, and determine the potential impact on the delivery and affordability of affordable housing. Through a rigorous literature review, as well as surveys and interviews with relevant stakeholders, this study was able to provide valuable insights into the role of innovative technologies in the affordable housing sector in South Africa.

5.3.1 Identifying the issues facing the delivery of affordable housing in SA

The research utilised a combination of literature review and interviews with relevant stakeholders to gain insights into the key issues in the affordable housing market. The literature review identified several issues stemming from the rapid urbanisation of the country, including a shortage of affordable housing supply and a rising backlog of affordable housing demand. These issues have resulted in households living in poor conditions with inadequate sanitation and unsafe environments. Poor supply chain management and minimal collaboration and cooperation were also identified as contributing factors to the challenges faced by the affordable housing sector in South Africa. In addition to the literature review, surveys and interviews were conducted to address this issue. The results highlighted issues such as high land costs, delays in affordable housing development caused by miscommunication or bureaucratic issues, and a lack of technological adoption and poor monitoring systems as major challenges faced by the delivery of affordable housing in South Africa. Overall, this objective was successfully achieved by identifying and understanding the key challenges facing the delivery of affordable housing in South Africa.

5.3.2 Examining various innovative technologies that can be used in designing and constructing affordable housing.

To address this objective, the study conducted a comprehensive literature review to identify and examine various innovative technologies that can be utilised in designing and constructing affordable housing. Through the reviewing literature, the study revealed a wide range of innovative technologies such as BIM, GIS, Object Oriented Programming, Project Portfolio Management, Virtual Reality (VR), Augmented Reality (AR), Artificial Intelligence, Unmanned Aerial Vehicles (UAVs), Smart Sensors, 3D Printers, and Modular Construction. The literature review provided an in-depth understanding of the potential benefits and limitations of each technology in improving the delivery process and affordability of affordable housing. By examining these technologies, the study was able to provide insights into the various options available for home developers to enhance the design and construction of affordable housing.

5.3.3 Determining the level of adoption of innovative technologies within South African affordable housing development.

The study utilised interviews and surveys to determine the current level of adoption of innovative technologies in the affordable housing sector in South Africa to address this objective. The results showed that while most home developers and companies were moderately familiar with the identified technologies, however, the level of usage was generally low to moderate. Specifically, technologies such as GIS, BIM, UAVs, Object Oriented Programming, 3D Laser Scanners, Smart Sensors, and 3D Printers displayed relatively low usage among the surveyed home developers. In contrast, modular construction was identified by most of the interviewed affordable housing experts as the technology that was most commonly used, however, the findings identify they show far less usage of the other mentioned technologies.

5.3.4 Identifying the advantages and disadvantages of using innovative technologies in South African affordable development.

To address this objective, a combination of literature review, interviews and surveys were utilised to identify the advantages and disadvantages of using innovative technologies in South African affordable housing development. The literature revealed that the use of innovative technologies can lead to long-term cost savings, increased efficiency in the construction process, improved quality of construction, and faster delivery of affordable housing units. For

example, technologies such as modular construction have been found to reduce construction time and costs, while 3D printers have the potential to revolutionise the construction industry by reducing construction time and material waste. However, the interviews and surveys also identified some disadvantages to the use of innovative technologies in South African affordable housing development. These include the initial high costs of acquiring and implementing these technologies, lack of skills and knowledge to operate the technology, and potential resistance from stakeholders due to a lack of social acceptance. Additionally, some interviewees expressed concerns about the impact of innovative technologies on job security for construction workers.

5.3.5 Determining the challenges and barriers to the adoption of innovative technologies within South African affordable housing projects.

Both literature review and interviews/surveys were utilised to identify challenges and barriers to the adoption of innovative technologies in South African affordable housing projects. The literature review identified challenges such as the lack of skills and knowledge in using innovative technologies, the high initial costs of investing in these technologies, and the resistance to change from traditional building methods. In addition, interviews and surveys were conducted with relevant stakeholders, such as home developers, and affordable housing experts to identify specific challenges they faced in adopting innovative technologies.
Similarly, the findings reveal that the high costs of adoption (including initial, maintenance and operational costs) as a significant challenge faced by stakeholders. The findings also reveal that the lack of technical knowledge is a large issue amongst the home developers which hinders its full adoption. The interviewed experts confess similar remarks, as well as the minimal social acceptance of innovative technology within South Africa between end-users, stakeholders and even the government.

5.3.6 Evaluating the impact that innovative technologies have on the delivery process and affordability of South African affordable housing.

To address this objective, the study utilised both literature and primary data sources. The literature review provided a theoretical basis for understanding the potential impact of innovative technologies on the delivery process and affordability of affordable housing in South Africa. The study found that innovative technologies such as modular construction, 3D printing, BIM, and GIS have the potential to improve the efficiency and quality of affordable housing delivery, reduce costs, and improve affordability. These technologies can speed up the construction process, improve collaboration and communication between stakeholders, reduce material waste, and enhance energy efficiency. Through surveys and interviews with home developers and affordable housing experts, the study evaluated the impact of innovative technologies on the delivery process and affordability of affordable housing. The findings indicated that while some technologies such as modular construction have been successfully implemented in affordable housing projects, the overall adoption and impact of innovative technologies on the affordability and delivery process of affordable housing in South Africa is still limited. The study suggests that addressing the challenges and barriers to the adoption of innovative technologies is crucial to realising their potential benefits in the affordable housing sector.

5.4 Examining The Research Hypothesis:

The study formulated two hypotheses to examine the impact of utilising innovative technologies on the perceived affordability and efficiency of affordable housing. However, the results of the Kruskal-Wallis test present a contrasting outcome that challenges the initial

hypotheses. Surprisingly, the analysis indicates that the majority of the assessed technologies, including BIM, GIS, 3D Laser Scanners, Drones, 3D Printers, and OOP, do not demonstrate a statistically significant influence on the perceived efficiency or affordability of affordable housing. This contradicts the first hypothesis, which anticipated a substantial impact resulting from the utilisation of innovative technologies. Instead, these findings align with the null hypothesis (H0), suggesting that the level of technology utilisation does not significantly affect the perceived efficiency of the delivery process in affordable housing. Interestingly, the Kruskal-Wallis test uncovers a statistically significant relationship involving Smart Sensors, indicating their significant impact on the delivery rate of affordable housing. This outcome deviates from the null hypothesis and supports the assertion that the utilisation of Smart Sensors holds considerable influence in enhancing the efficiency of affordable housing projects. Regarding the second hypothesis, the test reveals that only Modular Construction, OOP, and PPM exhibit statistically significant relationships with the delivery rate and affordability of affordable housing. Consequently, the null hypothesis (H0) is rejected in favour of the alternative hypothesis (H1), implying that the utilisation of these specific technologies significantly affects the affordability of affordable housing projects. The findings derived from the Kruskal-Wallis test do not align with the initial hypotheses. While certain technologies, such as Smart Sensors, Modular Construction, OOP, and PPM, exhibit potential for driving improvements in affordability and efficiency, the overall impact of innovative technologies on affordable housing is not as substantial as initially hypothesised. Consequently, these results emphasise the importance of carefully evaluating and analysing individual technologies within the context of affordable housing design and construction.

5.5 Conclusion

This study has highlighted the persistent issue of the affordable housing backlog in South Africa, which is expected to increase annually. The findings of the study indicate that poor delivery systems and inefficiencies in the supply chain processes of construction companies are major contributors to this problem. The literature review revealed that supply chain inefficiencies can significantly impact the rate at which affordable housing is delivered. Home developers surveyed in the study revealed that delays in affordable housing development are a recurring problem, with inefficient monitoring of construction projects, miscommunication and ineffective collaboration between the design team and construction team, and a lack of technological adoption being the top three reasons for these delays. It is clear from the literature that these issues stem from a mismanaged supply chain process in construction companies. Furthermore, the study also examined the affordability of affordable housing in South Africa. While affordable housing is meant to provide financial support to households in need, the research findings revealed that these housing types are not necessarily affordable. The study deduced that households earning between R3501 and R22 000 per month should be able to pay for affordable houses if the housing cost does not exceed 30% of their monthly income. However, the research findings indicate that the process of affordable housing delivery tends to be expensive due to the high costs of materials, expensive land, and government red tape, which prolongs the delivery process. The longer a project takes to complete, the higher the cost of development, further impacting the affordability of affordable housing.

The findings of this study indicate that the South African housing sector is facing a significant challenge with the delivery and affordability of affordable housing, leading to an increase in slum-like living conditions for migrating households. The adoption of innovative technology has been identified as a potential solution to address these issues, as highlighted in the literature review and supported by the research findings. The majority of South African home developers believe that the utilisation of innovative technology in affordable housing design and

construction can result in faster delivery, reduced rework, and improved project monitoring. This is consistent with the literature that suggests the usage of innovative technology can lead to improved delivery rates, lower production costs, and decreased rework during construction. Specific innovative technologies, such as Project Portfolio Management, BIM, Modular Construction, and 3D printing, have been found to significantly reduce costs and improve delivery speed. Moreover, the usage of BIM, Modular Construction, and 3D Printing can improve efficiency, avoid errors, and assist with clash detection. Other technologies, such as VR, AR, Artificial Intelligence, GIS, and Object-Oriented Programming, can provide more detailed visualisations and real-time data sharing, thus enabling stakeholders to plan and design cohesively with minimal errors.

The study reveals that innovative technologies have the potential to improve the delivery and affordability of affordable housing in South Africa. However, research findings also suggest that the adoption of innovative technologies poses significant challenges. The majority of surveyed home developers acknowledge the advantages of innovative technologies, yet the adoption rate remains low due to high adoption costs and a lack of technical knowledge. The literature highlights that newer technologies such as 3D Printing, VR, AR, and Artificial Intelligence are particularly expensive to adopt and maintain, while these technologies are not extensively taught in tertiary education systems, which further limits technical knowledge. Although home developers demonstrate fair awareness of these technologies, further training and higher costs for adoption are required to adopt them. As a result, home developers indicate a slightly higher usage of Project Portfolio Management systems, BIM, GIS, and Modular Construction technologies and less usage of other technologies in South Africa. Nonetheless, the adoption rate of innovative technologies in the country remains significantly low compared to other first-world countries. Apart from the high costs and lack of technical awareness, the study highlights another critical challenge: social acceptance. Many innovative technologies face opposition from stakeholders and end-users who consider them "substandard" compared to traditional brick-and-mortar houses, despite their structural soundness. Research findings reveal that some of these technologies are used as building methods for upper-market housing in developed nations but are being utilised only for affordable housing schemes in South Africa. To increase buy-in from stakeholders and end-users, the government should incentivise the use of these technologies in upper-market households by private companies to help set standards for home development in the country. This approach could raise social acceptance and result in the increased usage of innovative technologies in affordable housing schemes. After a thorough analysis of the data and literature, the study concludes that the adoption of innovative technologies has significant potential in improving the delivery and affordability of affordable housing in South Africa. Innovative technologies such as Project Portfolio Management, BIM, GIS, Modular Construction, and 3D Printing have the potential to bring down costs, increase delivery speed and efficiency, and avoid construction errors. However, the study found that the adoption of these technologies is hindered by the high costs of adoption and maintenance, as well as the lack of technical knowledge among professionals. The issue of social acceptance also plays a role in the limited adoption of innovative technologies in affordable housing.

5.6 Research Recommendations

To enhance the adoption of innovative technologies and improve affordable housing delivery, it is crucial for stakeholders in the affordable housing sector to prioritise specific recommendations tailored to their roles and responsibilities.

5.6.1 Home Developers:

- Embrace Project Portfolio Management systems, Building Information Modelling (BIM), Geographic Information Systems (GIS), Modular Construction, Smart Sensors,

OOP, and PPM as key technologies to enhance project planning, coordination, and construction efficiency. Explore their potential benefits and invest in training programs to ensure proficiency and maximise utilisation.

- Foster collaboration and knowledge-sharing among home developers by establishing industry forums or associations dedicated to promoting the adoption and best practices of innovative technologies. Encourage the exchange of experiences, lessons learned, and successful implementation strategies to facilitate collective growth and progress.

5.6.2 Government

- Provide incentives, such as tax breaks or subsidies, to incentivise home developers, particularly in the upper-market housing sector, to adopt innovative technologies. By setting a precedent and demonstrating the advantages of these technologies, the government can encourage wider industry adoption.
- Allocate resources and funding for training and education programs to address the current lack of technical knowledge and skills required for effective technology implementation. Develop partnerships with educational institutions and training providers to ensure accessible and relevant training opportunities for industry professionals.
- Collaborate with industry associations and research institutions to establish guidelines, standards, and regulations that support the integration and utilisation of innovative technologies in affordable housing projects. These frameworks will help streamline processes, ensure quality control, and foster innovation in the sector. Furthermore, the government should implement policies that incentivise the adoption of these technologies through tax breaks, grants, and subsidies, making it financially viable for developers to invest in innovative solutions.
- Additionally, government interventions and regulatory frameworks could play a crucial role in facilitating the adoption of innovative technologies in affordable housing. Implementing supportive policies and providing incentives for technology adoption can significantly lower barriers such as high adoption costs and lack of technical knowledge, thereby enhancing the practical relevance of these recommendations.

5.6.3 Addressing High Adoption Costs and Technical Knowledge Gaps

- Stakeholders should seek partnerships with technology providers to negotiate better pricing and facilitate bulk purchasing, which can reduce the high costs associated with innovative technology adoption.
- Additionally, investing in comprehensive training programs for current and future professionals in the construction industry will bridge the technical knowledge gap and ensure the effective implementation and maintenance of these technologies.

5.6.4 Professionals and Industry Associations:

- Actively seek training opportunities and professional development programs to stay updated with the latest advancements in innovative technologies. Engage in knowledge-sharing forums, conferences, and workshops to exchange insights and best practices among professionals within the industry.
- Advocate for the importance of innovative technologies within the affordable housing sector. Promote awareness and understanding of the benefits and potential of these technologies through publications, presentations, and industry events. Collaborate with

industry associations to drive initiatives that promote the adoption and integration of innovative technologies.

5.6.5 End Users and Communities

- Increase social acceptance and understanding of innovative technologies through targeted marketing and education campaigns. Highlight the benefits, such as improved energy efficiency, enhanced comfort, and cost savings, to generate interest and positive perceptions among end users and communities.
- Involve end users in the decision-making process by seeking their input and feedback during the design and planning stages. By incorporating their needs and preferences, the adoption of innovative technologies can be better aligned with the requirements of affordable housing occupants.
- Provide accessible information and resources to end users and communities to ensure a seamless transition and optimal utilisation of innovative technologies. Develop user-friendly guides, manuals, and online platforms that offer comprehensive information on the technologies implemented, their maintenance requirements, and potential cost-saving measures.

By implementing these recommendations, stakeholders in the affordable housing sector can drive the widespread adoption of innovative technologies, leading to improved efficiency, cost reduction, and meeting the housing needs of the population more effectively.

5.7 Future research directions or areas for improvement

This study has highlighted several future research directions and areas for improvement in the South African affordable housing sector. Future research should focus on exploring the feasibility and long-term impacts of implementing innovative technologies with lower adoption rates to enhance efficiency and affordability in the housing market. Additionally, the integration of these technologies with sustainable building practices could be examined to maximise environmental benefits. Given the socio-cultural barriers and the lack of technical knowledge among professionals, research could investigate the potential for training and education programs to improve technical awareness, encourage innovation, and address social acceptance strategies that could increase the adoption of these technologies within different communities. Furthermore, there is a need to study the influence of government regulations and policies on the adoption and effectiveness of innovative technologies. Comparative studies between South Africa and other developing nations could also offer broader perspectives and identify best practices. Finally, the role of public-private partnerships in facilitating the adoption of these technologies and improving the affordability and delivery of housing should be explored to provide comprehensive strategies for advancing the sector.

5.8 Significance of the Research

The present study offers a comprehensive analysis of the challenges facing the delivery and affordability of affordable housing in South Africa. The study's key finding highlights the lack of efficient delivery systems and supply chain processes in construction companies that result in delayed affordable housing development. Moreover, the research reveals that affordable housing, designed to provide financial support to households in need, is not necessarily affordable, as the process of delivery tends to be expensive due to high material and land costs and government red tape. This study also identifies innovative technologies, such as Project Portfolio Management, BIM, GIS, Modular Construction, and 3D Printing, as potential solutions that could improve delivery rates and reduce construction costs. However, the

research indicates that the adoption of innovative technologies poses significant challenges due to high costs and the lack of technical knowledge. Moreover, social acceptance has been identified as a significant challenge in the adoption of innovative technologies in affordable housing schemes. Finally, the present study offers critical insights into the challenges facing the affordable housing sector in South Africa and the potential solutions that could improve the delivery and affordability of affordable housing. The study contributes to the existing literature by identifying innovative technologies that could significantly reduce construction costs and improve delivery rates, thus contributing to a reduction in the affordable housing backlog in South Africa. The study's significance lies in its ability to provide policymakers, construction companies, and affordable housing experts with critical insights and solutions that could improve the delivery and affordability of affordable housing in South Africa. Furthermore, the study provides future researchers with an opportunity to explore innovative technologies further and their potential impact on the affordable housing sector. The significance of this research extends beyond identifying challenges and proposing solutions within South Africa. By addressing the barriers to technology adoption and exploring the role of innovative technologies, this study contributes to the broader field of affordable housing research globally. The insights gained can inform policy development, strategic planning, and practical implementations in other developing nations facing similar issues, thereby advancing the field of affordable housing research both within South Africa and on a global scale.

LIST OF REFERENCES

Abdul-Rahman, H., Wang, C., Wood, L. C. & Khoo, Y. M., 2014. Defects In Affordable Housing Projects In Klang Valley, Malaysia. *Journal of Performance of Constructed Facilities*, pp. 1-42.

Aerd Statistics, 2018. *Kruskal-Wallis H Test using SPSS Statistics.* [Online] Available at: https://statistics.laerd.com/spss-tutorials/kruskal-wallis-h-test-using-spss-statistics.php#:~:text=The%20Kruskal%2DWallis%20H%20test,continuous%20or%20ordinal%20dependent%20variable. [Accessed 1 March 2023].

Aerd Statistics, 2018. *Testing for Normality using SPSS Statistics.* [Online] Available at: https://statistics.laerd.com/spss-tutorials/testing-for-normality-using-spss-statistics.php#:~:text=value%20of%20the%20Shapiro%2DWilk,enhanced%20testing%20for%20normality%20guide. [Accessed 1 March 2023].

Akinradewo, O. et al., 2021. Modular method of construction in developing countries: the underlying challenges. *International Journal of Construction Management, pp 23.*

Ali, M., Ullah, S. & Khan, P., 2009. Managing Innovation and Technology in Developing Countries. *arXiv preprint,* Volume 0911.1514.

Ali, S. et al., 2023. Ebola, informal settlements, and the role of place in infectious disease vulnerability: Evidence from the 2014–16 outbreak in urban Sierra Leone. *Disasters,* Volume 47, pp. 389-411.

Almukhtar, A., Saeed, Z. O., Abanda, H. & Tah, J. H. M., 2021. Reality Capture of Buildings Using 3D Laser Scanners. *CivilEng,* Volume 2, pp. 214-235.

Amin, M. & Noori, A., 2016. Mechanism for farm mechanization and careful planning using geographic information system (GIS). *J. Bus. Technovation,* Volume 4, pp. 23-28.

Amirebrahimi, S., Rajabifard, A., Mendis, P. & Ngo, T., 2016. A BIM-GIS integration method in support of the assessment and 3D visualisation of flood damage to a building. *J. Spat. Sci,* Volume 61, pp. 317-350.

Anacker, K. B., 2019. Introduction: housing affordability and affordable housing. *INTERNATIONAL JOURNAL OF HOUSING POLICY,* 19(1), pp. 1-16.

Arashpour, et al., 2014. Analysis of Disruptions Caused by Construction Field Rework on Productivity in Residential Projects. *Journal of Construction Engineering and Management,* 140(2), p. 4013053.

Arayici, Y. A., Hamilton, A. & Gamito, P., 2006. Modelling 3D Scanned Data to Visualise and Analyse the Built Environment for Regeneration. *Surveying and Built Environment,* 17(2), pp. 7-28.

Asadi, K. et al., 2020. An integrated UGV-UAV system for construction site data collection", Automation in Construction. Volume 112(5), p. 103068.

Asha Rani, M., Kavana, M. D., Parvathy, S. J. & Shreelakshmi, C. M., 2017. Object-Oriented Programming and its Concepts. *IJSRD - International Journal for Scientific Research & Developm*, 5(9), pp. ISSN (online): 2321-0613.

Attride-Striling, J., 2001. Thematic Networks: an analytic tool for qualitative research.. *Qualitative Research,* 1(3), pp. 358-405.

Azuma, R. et al., 2001. Recent advances in augmented reality. *IEEE Comp*, Volume 21, pp. 34-47.

Baeza, E., 2018. Applications of Virtual Reality in Construction. *Core*, pp. 1-6.

Barbosa, M. W. & Rodrigues, C. d. Á., 2020. Project Portfolio Management teaching: Contributions of a gamified approach. *The International Journal of Management Education*, Volume 18, pp. 1-13.

Benna, U. & Garba, S. e., 2016. *Population Growth and Rapid Urbanization in the Developing World*. s.l.: IGI Global.

Bennett, A., Cuff, D. & Wendel, G., 2019. Backyard Housing Boom: New Markets for Affordable Housing and the Role of Digital Technology. *Technol. Archit. Des*, Volume 3, pp. 76-88.

Bertram, N. et al., 2019. Modular construction: From projects to products. *McKinsey & Company*, pp. *1-34*.

Blengini, G. & Garbarino, E., 2010. Resources and waste management in Turin (Italy): The role of recycled aggregates in the sustainable supply mix. *J. Clean. Prod*, Volume 18, pp. 1021-1030.

Bodo, T., 2019. Rapid Urbanisation: Theories, Causes, Consequences and Coping Strategies. *Sryahwa*, 2(3), pp. 32-45.

Brahman, R., 2017. Object-Oriented Programming: Advantages and Disadvantages. *International Journal of Computer Applications*, 176(9), pp. 15-18.

Brooks, C., 2022. *How Virtual Reality Is Changing Construction?* [Online] Available at: https://www.business.com/articles/how-virtual-reality-is-changing-construction/ [Accessed 27 October 2022].

Bryde, D., Broquetas, M. & Volm, J. M., 2013. The project benefits of Building Information Modelling (BIM). *Elsevier*, Issue 31, pp. 971-980.

Buchanan, C. & Gardner, L., 2019. Metal 3D printing in construction: A review of methods, research, applications, opportunities and challenges. *Elsevier*, pp. 332-348.

Bui, N., Merschbrock, C. & Munkvold, B. E., 2016. A review of Building Information Modelling for construction in developing countries. *Elsevier*, Issue 164, pp. 487-494.

Bujang, M. A. & Baharum, N., 2017. A simplified guide to determination of sample size requirements for estimating the value of intraclass correlation coefficient: a review. *The Journal of the School of Dental Sciences, USM*, 12(1), pp. 1-11.

Buswell, R., Soar, R., AGF, G. & Thorpe, A., 2007. A Freeform construction: mega-scale rapid manufacturing for construction. *Autom Constr*, Issue 16, pp. 224-231.

Carrington, D., 2015. *World population to hit 11bn in 2100 – with 70% chance of continuous rise.* [Online] Available at: http://www.geohive.com/earth/population_now.aspx [Accessed 2 August 2022].

Carswell, A., 2021. *The Encyclopedia of Housing.* CA, USA: SAGE Publications: Thousand Oaks, Volume 1-2, https://doi.org/10.4135/9781452218380.

Cerga, R., 2022. *How Virtual Reality is set to change the construction industry.* [Online] Available at: https://www.bbntimes.com/technology/how-virtual-reality-is-set-to-change-the-construction-industry [Accessed 1 November 2022].

Chakwizira, J., 2019. Low-Income Housing Backlogs and Deficits “Blues” in South Africa. What Solutions Can a Lean Construction Approach Proffer?. *Journal of Settlements and Spatial Planning,* Volume 10, pp. 71-88.

Cho, E. & Kim, S., 2015. Cronbach’s Coefficient Alpha: Well-Known but Poorly Understood. *Organizational Research Methods,* 18(2), pp. 207-230.

Cipresso, P., Giglioli, I., Raya, M. & Riva, G., 2018. The Past, Present, and Future of Virtual and Augmented Reality Research: A Network and Cluster Analysis of the Literature. *Front Psychol,* 6(9), DOI=10.3389/fpsyg.2018.02086.

Creswell, J. W., 2014. Research Design: Qualitative, Quantitative and Mixed Methods Approaches (4th ed.). thousand *Oaks, CA: Sage.*

Currie, J. & Tekin, E., 2015. Is there a link between foreclosure and health? *American Economic Journal: Economic Policy,* 7(1), pp. 63-94.

Davenport, T., Loucks, J. & Schatsky, D., 2017. *Bullish on the Business Value of Cognitive.* [Online] Available at: https://www2.deloitte.com/us/en/pages/deloitte-analytics/articles/cognitive-technology-adoption-survey.html [Accessed 2 November 2022].

De Villiers, W. &. N. A., Boshoff, W., Brewis, C. & Brits, J., 2013. Full life cycle analysis of the environmental impact of low-cost housing in South Africa. *Conference: International Housing Conference.*

Del Rio, D. & Sovacool, B., 2023. Of cooks, crooks and slum-dwellers: Exploring the lived experience of energy and mobility poverty in Mexico’s informal settlements. *World Dev,* Volume 161, p. 106093.

Delux Modular, 2019. *The differences between prefab and modular construction.* [Online] Available at: https://ibuilt.com/?q=d [Accessed 10 November 2022].

Desmond, M., 2016. Evicted: Poverty and Profit in the American City. *New York: Crown Publishers.*

Di Giulio, R., Turillazzi, B., Marzi, L. & Pitzianti, S., 2017. Integrated BIM-GIS based design for high energy efficiency hospital buildings. *TECHNE-J. Technol. Archit. Environ,* pp. 243-255.

Dick, S., 2019. Artificial Intelligence. *Harvard Data Science Review,* Volume 1, pp. 1-9 https://doi.org/10.1162/99608f92.92fe150c.

Elghaish, F. et al., 2021. Toward digitalization in the construction industry with immersive and drones technologies: a critical literature review. *Smart and Sustainable Built Environment,* 10(3), pp. 345 - 363.

Ellen, I. G. & Lacoe, J., 2015. The impact of foreclosures on neighborhood crime. *Washington, DC: U.S. Department of Justice.*

Ellis, G., 2022. *The Power of Augmented Reality (AR) in Construction.* [Online] Available at: https://constructionblog.autodesk.com/augmented-reality-ar-construction/ [Accessed 1 November 2022].

Farnsworth, C. B., Beveridge, S., Miller, K. R. & Christofferson, J. P., 2015. Application, Advantages, and Methods Associated with Using BIM in Commercial Construction. *International Journal of Construction Education and Research,* Issue 11:3, pp. 218-236.

Fernandes, A., 2019. A Review on the Use of Object-Oriented Programming in Construction Management. *Journal of Construction Engineering and Management,* 145(12), 04019073.

Ferrada, X. & Serpell, A., 2014. Selection of construction methods for construction projects: A knowledge problem. *Journal of Construction Engineering and Management.,* 140(4), B4014002-1. 10.1061/(ASCE)CO.1943-7862.0000715.

Fong, D. & Shahparvari, M., 2018. The Review of Rework Causes and Costs in Housing Construction Supply Chain. *Group for Lean Construction (IGLC), González, V.A. (ed.),* pp. 1375–1384.

Fowler, K. A. et al., 2015. Increase in suicides associated with home eviction and foreclosure during the US housing crisis: Findings from 16 national violent death reporting system states, 2005-2010.. *American Journal of Public Health,* 105(2), pp. 311-316.

Fröhlich, C. & Mettenleiter, M., 2004. Terrestrial laser scanning–new perspectives in 3D surveying. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci,* Volume 36.

Gerges, M., Ahiakwo, O., Jaeger, M. & Asaad, A., 2016. Building Information Modeling and Its Application in the State of Kuwait. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering,* Volume Volume 10 (1), pp. 81-86.

Glaeser, E. & Joshi-Ghani, A., 2013. Rethinking cities: Towards shared prosperity. *Economic Premise* Volume 126, pp. 1-14.

Greenwood, W., Lynch, J. & Zekkos, D., 2019. Applications of UAVs in civil infrastructure. *Journal of Infrastructure Systems,* 25(2), 04019002.

Heinzel, A., Azhar, S. & Nadeem, A., 2017. *Uses of Augmented Reality Technology during Construction Phase.* Dubai, United Arab Emirates, in The Ninth International Conference on Construction in the 21st Century (CITC-9) Revolutionizing the Architecture, pp. 1-8.

Hoínková, D., 2021. Advantages and Disadvantages of Modular Construction, including Environmental Impacts. *IOP Conf. Ser.: Mater. Sci. Eng,* 1203(032002), pp. doi:10.1088/1757-899X/1203/3/032002.

Irizarry, J. & Costa, D., 2016. Exploratory study of potential applications of unmanned aerial systems for construction management tasks. *Journal of Management in Engineering,* 32(3), doi:10.1061/(ASCE)ME.1943-5479.0000422.

Jakabovics, A., Ross, L. M., Spotts, M. & Simpson, M., 2014. Bending the cost curve: Solutions to expand the supply of affordable rentals. *Washington, DC: Urban Land Institute,* pp. 1-43.

Jeaune, K. L., Moghayedi, A., Massyn, M. & Bryon, P., 2021. Establishing the Indicators of Sustainable Building Materials. *Emerging Technologies and Applications for Green Infrastructure,* Volume 203, pp.617-625.

Jerbrant, A. & Karrbom Gustavsson, T., 2013. Managing project portfolios: Balancing flexibility and structure by improvising. *International Journal of Managing Projects in Business,* 6(1), pp. 152-172.

Jones, A. & Stead, L., 2020. Can People on Low Incomes Access Affordable Housing Loans in Urban Africa and Asia? Examples of Innovative Housing Finance Models from Reall's Global Network. *Environ.,* Volume 32, pp. 1-9.

Kim, J., 2015. Advantages and Disadvantages of Object-Oriented Programming. *International Journal of Scientific and Engineering Research,* 6(7), pp. 1236-1239.

Leal, R. et al., 2017. Additive manufacturing tooling for the automotive industry. *Int. J Manuf Technol,* Issue 92, pp. 1671-1672.

Lee, Y., 2016. A Comparison of Object-Oriented Programming and Other Programming Paradigms. *International Journal of Computer Science and Information Technology,* 8(4), pp. 267-271.

Lennartz, C., 2017. Housing wealth and welfare state restructuring: Between asset-based welfare and the social investment strategy. *Housing Wealth and Welfare*, pp. 108–131.

Liu, S., Xie, B., Tivendale, L. & Liu, C., 2015. The driving force of government in promoting BIM implementation. *Journal of Management and Sustainability,* Volume [e-journal] Volume 5 (4), pp. 157-164.

Lopez, J., 2019. Object-Oriented Programming: An Overview. *International Journal of Computer Science and Information Technology,* 11(4), pp. 201-206.

Lu, X. et al., 2017. A State-of-the-Art Review on the Integration of Building Information Modeling (BIM) and Geographic Information System (GIS). *ISPRS Int. J. Geo-Inf.*, 6(53), https://doi.org/10.3390/ijgi6020053.

Lynn, R., 2022. *Project Portfolio Management Defined.* [Online] Available at: https://www.planview.com/resources/guide/project-management-office-ppm-best-practices/project-portfolio-management-defined/ [Accessed 8 December 2022].

Mahachi, J., 2021. Innovative building technologies 4.0: Fast-tracking housing delivery through 3D printing. *S Afr J Sci*, 117(11/12), pp.1-5.

Malina, M. A., Nørreklit, H. S. & Selto, F. H., 2011. Lessons learned: advantages and disadvantages of mixed method research. *Qualitative Research in Accounting & Management,* 8(1), pp. 59-71.

Maliszewska, M., Mattoo, A. & Mensbrugghe, v. d., 2020. The Potential Impact of COVID-19 on GDP and Trade: A Preliminary Assessment. *World Bank Policy Research Working Paper*, Volume 9211, pp. 26.

Manomano, T., Tanga, P. T. & Perpetua, T., 2017. Housing Problems and Programs in South Africa: A Literature Review. *Journal of Sociology and Social Anthropology,* 7(2), pp. 111-117.

Marin, D., 2018. Object-Oriented Programming: Principles and Practice. *International Journal of Computer Science and Information Technology,* 10(1), pp. 1-5.

Martinez, E., Reid, C. & Tommelein, I., 2019. Lean Construction for Affordable Housing: A Case Study in Latin America. *Constr. Innov*, Volume 19(4), pp. 570-593.

Martinsuo, M., Korhonen, T. & Laine, T., 2014. Identifying, framing and managing uncertainties in project portfolios. *International Journal of Project Management,* 35(4), pp. 732–746.

Marutlulle, N. K., 2021. A critical analysis of housing inadequacy in South Africa and its ramifications. *AOSIS,* 9(1), p. 372, https://doi.org/10.4102/apsdpr.v9i1.372.

Massyn, M., Moghayedi, A., Jeune, K. L. & Michell, K., 2022. Evaluating the Awareness, Barriers, and Level of Adoption of Innovative Digital Technologies in the Health and Safety of High-Rise Construction in South Africa. *The Twelfth International Conference on Construction in the 21st Century (CITC-12)*, pp. 1-10.

Mbandlwa, Z., 2021. Challenges of the low-cost houses in South Africa. *Social Psychology of Education,* 58(2), pp. 6753-6766.

McKinsey, 2019. *Modular construction: From projects to products.* [Online] Available at: https://www.mckinsey.com/capabilities/operations/our-insights/modular-construction-from-projects-to-products [Accessed 10 November 2022].

Mishra, A., 2017. Comparative Performance Assessment of Conventional Buildings of Kathmandu. *International Journal of Current Research,* Volume 9, pp. 62958-62973.

Mlambo, V., 2018. An overview of rural-urban migration in South Africa: its causes and implications. *Archives of Business Research,* 6(4), pp. 63-70.

Moghayedi, A., 2016. Improving Critical Path Method (CPM) by applying safety factors to manage delays. *Scientia Iranica A* , 23(3), pp. 815-826.

Moghayedi, A. et al., 2021. A Critical Success Factor Framework for Implementing Sustainable Innovative and Affordable Housing: A Systematic Review and Bibliometric Analysis. *Buildings 2021,* 11(317).

Moghayedi, A., Massyn, M., Jeune, K. L. & Michell, K., 2023. Influential Factors Affecting the Diffusion of Building Information Modeling in South African Construction Projects. The *University of Cape Town,* pp. 1-9.

Moghayedi, A., Mehmood, A., Michell, K. & Ekpo, C. O., 2023. Modelling the Neighborhood Wellbeing of Townships in South Africa. *Sustainability,* 15(11), p. 8542.

Moghayedi, A. & Windapo, A., 2019. Key Performance Criteria Influencing the Selection of Construction Methods Used for the Fabrication of Building Components in the Middle East. *Sustainable Construction and Building Materials.,* DOI: 10.5772/intechopen.81673.

Monghasemi, S., Nikoo, M., Fasaee, M. & Adamowski, J., 2015. A novel multi-criteria decision-making model for optimizing time–cost–quality trade-off problems in construction projects. *Expert Systems with Applications.,* 42(6), pp. 3089-3104.

Mortice, Z., 2019. *Can this Chicago apartment factory make new homes affordable?* [Online] Available at: https://www.citylab.com/design/2019/07/chicago-new-construction-apartment -affordable-rent-skender/592444/ [Accessed 10 November 2022].

Mulliner, E., Malys, N. & Maliene, V., 2016. Comparative analysis of MCDM methods for the assessment of sustainable housing affordability. *Omega,* Volume 59, pp. 146-156.

Nassereddine, H., Hanna, A. S., Veeramani, D. & Lotfallah, W., 2022. Augmented Reality in the Construction Industry: Use-Cases, Benefits, Obstacles, and Future Trends. *Frontiers in Built Environment,* Volume 10.3389/fbuil.2022.730094.

National Geographic, 2022. *GIS (Geographic Information System).* [Online] Available at: https://education.nationalgeographic.org/resource/geographic-information-system-gis/10th-grade/ [Accessed 3 November 2022].

Nichols, M. R., 2020. *Smart Sensors are a game changer for the construction industry.* [Online] Available at: https://www.euroscientist.com/smart-sensors-are-a-game-changer-for-the-construction-industry/#:~:text=In%20a%20construction%20setting%2C%20smart,new%20pour%20is%20done%20curing. [Accessed 9 November 2022].

Ntongana, T., 2016. five *years building an RDP house and still not finished.* [Online] Available at: https://www.groundup.org.za/article/five-years-building-rdp-house-and-still-not-finished/ [Accessed 02 May 2023].

Nunnally, J. & Bernstein, I., 1994. *Psychometric Theory.* 3rd edition ed. New York: McGraw Hill: s.n.

Omer, M. A. & Noguchi, T., 2020. A conceptual framework for understanding the contribution of building materials in the achievement of Sustainable Development Goals (SDGs). *Sustainable Cities and Society,* Volume 52, p. 101869.

Osunsanmi, T., Aigbavboa, C. & Oke, A., 2018. Construction 4.0: The Future of the Construction Industry in South Africa. *Int. J. Civ. Environ. Eng.,* Volume 12, pp. 206-212.

Owolabi, J. D. et al., 2014. Causes and Effect of Delay On Project Construction Delivery Time. *International Journal of Education and Research,* pp. 197-208.

Pärn, E. & Edwards, D., 2017. Conceptualising the FinDD API plug-in: A study of BIM-FM integration. *Autom. Constr,* Volume 80, pp. 11-21.

PD&R EDGE, 2022. *Using Technological Innovations To Lower Housing Construction Costs.* [Online] Available at: https://www.huduser.gov/portal/pdredge/pdr-edge-featd-article-053122.html [Accessed 18 October 2022].

Perera, U. & Lee, P., 2021. A relational lens to understand housing affordability in the 21st Century. *Journal of Urban Management,* Volume 10, pp. 314-324.

Peterson, K., 2018. Backdoor revolution: The definitive guide to ADU development. *Portland, OR: Accessory Dwelling Strategies.*

Petit, Y., 2012. Project portfolios in dynamic environments: Organizing for uncertainty. *International Journal of Project Management,* 30(5), p. 539–553.

PMI, 2017. *Project management body of knowledge (PMBOK® guide).* Newtown Square, PA, USA: s.n.

Pole, K., 2007. Mixed Methods Designs: A Review of Strategies for Blending Quantitative and Qualitative Methodologies. *Academia,* 20(4), pp. 1-5.

Posey, B., 2022. *Smart Sensor.* [Online] Available at: https://www.techtarget.com/iotagenda/definition/smart-sensor [Accessed 9 November 2022].

Rao, S., 2022. *The Benefits of AI In Construction.* [Online] Available at: https://constructible.trimble.com/construction-industry/the-benefits-of-ai-in-construction [Accessed 2 November 2022].

Richardson, V., 2017. 3D printing becomes concrete: exploring the structural potential of concrete 3D printing. *The Structural Engineer,* Volume 95, pp. 8.

Robert H. Smith School of Business, 2023. *What Is Supply Chain Management, and Why Is It Important?* [Online] Available at: https://onlinebusiness.umd.edu/mba/resources/what-is-supply-chain-management-and-why-is-it-important/#:~:text=Why%20Is%20Supply%20Chain%20Management,market%2C%20and%20ultimately%20to%20consumers. [Accessed 20 February 2023].

SA Home Loans, 2022. *FLISP: The 2022 Guide to the Government Housing Subsidy.* [Online] Available at: https://www.sahomeloans.com/bond-talk/flisp-2022-guide-government-housing-subsidy [Accessed 02 May 2023].

Sakin, M. & Kiroglu, Y. C., 2017. 3D Printing of Buildings: Construction of the Sustainable Houses of the Future by BIM. *Elsevier,* Issue SEB-17, pp. 702-711.

Salvi del Pero, A., Adema, W., Ferraro, V. & Frey, V., 2016. Policies to promote access to good-quality affordable housing in OECD countries. *OECD Social, Employment and Migration Working Papers,* Volume 176, pp. 1-82.

Sanhudo, L. et al., 2020. A framework for in-situ geometric data acquisition using laser scanning for BIM modelling. *Journal of Building Engineering,* Volume 28, doi:10.1016/j.jobe.2019.101073.

Santos, F., 2020. Object-Oriented Programming for Construction Management: A Review. *Journal of Construction Engineering and Management,* 146(3), 04019101.

Seeliger, L. & Turok, I., 2014. Averting a downward spiral: Building resilience in informal urban settlements through adaptive governance. *Environment and Urbanisation,* 26(1), pp. 184-199.

Shahparvari, M., Robinson, H., Fong, D. & Ebohon, O. J., 2019. Improving affordable housing delivery through the reduction of rework in the supply chain. *London South Bank University,* pp. 1-11.

Sharifi, S., 2018. *3 Ways Virtual Reality in Construction is Shaping the Industry.* [Online] Available at: https://bim360resources.autodesk.com/connect-construct/3-ways-virtual-reality-in-construction-is-shaping-the-industry [Accessed 1 November 2022].

Shen, X. & Shirmohammadi, S., 2008. Virtual and Augmented Reality. In: *Encyclopedia of Multimedia.* Boston, MA.: Springer, pp. 962-967.

Sherman, R., 2017. Uneasy Street: The anxieties of Affluence. *Princeton, NJ: Princeton University Press.*

Shorten, A. & Smith, J., 2017. Mixed methods research: expanding the evidence base. *Evidence-Based Nursing,* Volume 20, pp. 74-75.

Smith, P., 2014. BIM Implementation - global strategies. Procedia Engineering. *Procedia Engineering,* Volume Volume 85 (1), pp. 482-492.

Sridhar, K. S., 2016. Costs and Benefits of Urbanization: The Indian Case. *ADBInstitute,* Volume 607, pp. 1-31.

Statista, 2021. *South Africa: Urbanization from 2010 to 2020.* [Online] Available at: https://www.statisa.com/statistics/455931/urbanization-in-south-africa [Accessed 11 August 2022]

Statistics South Africa, 2016. *Community Survey.* [Online] Available at: http://cs2016.statssa.gov.za/wpcontent/ uploads/2016/07/NT-30-06-2016-RELEASEfor- CS-2016- Statistical-releas 1-July-2016.pdf. Accessed on 28.05.2019 [Accessed 3 August 2022].

Statistics, 2017. *South Africa's Household Survey,* Pretoria: Government Publishers. *Statistical Release,* pp. 1-188.

Stats SA, 2022. *After two years, GDP returns to pre-pandemic levels.* [Online] Available at: https://www.statssa.gov.za/?p=15440 [Accessed 11 August 2022].

Stats SA, 2022. *The South African economy records a positive fourth quarter.* [Online] Available at: https://www.statssa.gov.za/?p=15214 [Accessed 11 August 2022].

Teo, T.-A. & Cho, K.-H., 2016. BIM-oriented indoor network model for indoor and outdoor combined route planning. *Adv. Eng. Inform,* Volume 30, pp. 268-282.

Thai, H.-T., Ngo, T. & Uy, B., 2020. A review on modular construction for high-rise buildings. *Structures,* Volume 28, pp. 1265-1290.

Thomson, J., 2019. Modular Construction: A solution to affordable housing challenges. *Cornell Real Estate,* Volume 17, pp. 90-7.

Thurairajah, N. & Goucher, D., 2013. Advantages and Challenges of Using BIM: a Cost Consultant's Perspective. *ASC Annual International Conference Proceedings*, pp. 1-8.

Tkáč, M. & Mésároš, P., 2019. Utilizing drone technology in the civil engineering. *Journal of Civil Engineering*, pp. 27-37.

Turok, I. & Borel-Saladin, J., 2014. Is urbanisation in South Africa on a sustainable trajectory? *Development Southern Africa*, 31(5), pp. 675-691.

UCLA, 2023. *What Does Cronbach's Alpha Mean? | Spss Faq.* [Online] Available at: https://stats.oarc.ucla.edu/spss/faq/what-does-cronbachs-alpha-mean/ [Accessed 20 February 2023].

United Nations Publications, 2012. Women and the right to adequate housing. *United Nations.*

'Utoikamanu, F., 2018. *Closing the Technology Gap in Least Developed Countries.* [Online] Available at: https://www.un.org/en/chronicle/article/closing-technology-gap-least-developed-countries [Accessed 18 October 2022].

Viljakainen, T., 2020. Adoption of Augmented Reality Solutions in Field Engineering and Maintenance: Drivers and Barriers for Organizations. *Arcada University*, pp. 1-84.

Windapo, A. & Moghayedi, A., 2017. Building material price differentiation across geographic locations in South Africa. *Management, Procurement and Law*, 170(MP6), p. 243–254.

Windapo, A. O. & Moghayedi, A., 2020. Adoption of smart technologies and circular economy performance of buildings. *Built Environment Project and Asset Management*, 10(4), pp. 585-601.

World Population Review, 2021. *Richest African Countries 2021.* [Online] Available at: https://worldpopulationreview.com/country-rankings/richest-african-countries [Accessed 18 October 2022]

World Population Review, 2021. *South Africa Population 2021 (Live).* [Online] Available at: https://worldpopulationreview.com/countries/south-africa-population [Accessed 18 October 2022]

Wortmann, A., Root, D. & Venkatachalam, S., 2016. Building Information Modelling (BIM) Standards and Specifications Around The World and Its Applicability To The South African AEC Sector: A Critical Review. *Research Gate*, pp. 1-16.

Yilmaz, A., 2016. Advantages and Disadvantages of Object-Oriented Programming. *International Journal of Computer Science and Mobile Computing*, 5(8), pp. 97-99.

Yin, R., 2013. Validity and Generalization in future case study evaluations. *Evaluation*, 19(3), pp. 321-332.

Yusof, N., Kamal, E. M., Kong-Seng, L. & Iranmanesh, M., 2014. Are Innovations Being Created or Adopted in the Construction Industry? Exploring Innovation in the Construction Industry. *Sage Journals.*

Zhang, X., 2018. A Comparison of Object-Oriented Programming and Other Programming Paradigms. *International Journal of Computer Science and Information Technology*, 10(2), pp. 113-117.

Zhang, X. Q., 2016. The trends, promises and challenges of urbanisation in the world. *Habitat International*, Volume 54, pp. 241-252.

Zhu, J., Write, G., Wang, J. & Wang, X., 2018. A Critical Review of the Integration of Geographic Information System and Building Information Modelling at the Data Level. *International Journal of Geo-Information*, 7(66), https://doi.org/10.3390/ijgi7020066.

Žukauskas, P., Vveinhardt, J. & Andriukaitienė, R., 2018. Philosophy and Paradigm of Scientific Research. *Management Culture and Corporate Social Responsibility, IntechOpen, London.*, pp. 121-139.

APPENDIX

Appendix A
Expert Interview Protocol:

Information sheet and consent form

Introduction
My name is Jeffrey Jr. Mahachi, and I am conducting research toward a master's degree. I am evaluating the impact of innovative technologies on the delivery and affordability of South African Affordable Housing and would like to invite you to participate in the project.

About the project
The project aims to examine the influence of innovative technologies on the delivery process of South African affordable housing and whether they can fast track the delivery of affordable housing and ensure the affordability of such houses.

Participation is voluntary
Please understand that you are not obligated and do not have to participate in this project. Your participation is entirely voluntary. The choice to participate is yours alone. If you choose not to participate, there will be no adverse consequences. If you choose to participate but wish to withdraw at any time, you will be free to do so, without negative consequences. However, I would be grateful if you would assist me by allowing me to interview you.

Expectations from participations
I will only ask you a few questions regarding the usage of innovative technologies within the gap housing sector, this should take 15 to 30 minutes. There is no financial obligation from the project or you as the participant. Therefore, there is no payment/reimbursement available. With your permission, I would record this interview however you do not agree that is still acceptable. I also need your consent to refer to this recording and any notes I may have taken for academic purposes including my project, academic conferences and possibly journal publications.

Benefits to participants
No indirect or indirect harm

Risk of harm to participants
No foreseen or unforeseen risks

Sharing and use of data

Data generated from the interview will be synthesised and used to answer the research questions set for this master's project, presented in conferences and may be published in journals.

Anonymity and confidentiality

By signing the consent form you agree to the terms stipulated in this consent sheet regarding the interview. If you are not comfortable with the terms, please make a note on the form.

Interviewee name: **Interviewee's signature:**

_____ _____

Date:

_____

Additional comments

_____

Participation Information Sheet

1. Research title
Evaluating The Impact of Innovative Technologies on the Delivery and Affordability of South African Affordable Housing.

2. What is the purpose of this research?
This research aims to examine the influence of innovative technologies on the delivery process of South African affordable housing and whether they can fast track the delivery of affordable housing and ensure the affordability of such houses.

3. What will the research involve for me?
Your participation will only involve a simple 30-45minute interview. The questions will focus on your experience in the affordable housing sector and whether you have experience using innovative technologies to develop such housing. This interview will be oral and will only require a clear recording that will be transcribed for analysis.

4. What are the possible benefits of taking part?
Any insights we can gain from your participation will be extremely useful in identifying the usefulness of innovative technologies and the effect it has on the affordability and delivery rate of affordable housing.

5. Am I eligible to participate in this survey?
This survey is only for SA based individuals who are aged 18 or over.

6. Do I have to take part, and can I withdraw my response from the research?
Participating in this study is entirely voluntary. You are free to not participate in this research at all. You have the right to exit at any point of the survey and we will delete your response from the dataset. There will be no consequences for failing to complete the survey. This data collection and research work are totally independent of the university's employment/ assessment. However, once you have submitted your completed survey responses, it is not possible to withdraw your data.

7. Will my taking part in the research be kept confidential and how will the data be processed?
Please bear in mind that no personally identifiable information will be required throughout the entire data collection. This data collection and research work are for our academic use only. Publication of research outputs or potential sharing of data with other research institutes will only take place after the thorough anonymisation and will not disclose any personally identifiable information.

8. Ethical approval
The research has been reviewed and approved by the University Research Ethics Committee of UCT, with the ethics reference number and permission have been obtained to circulate this survey.

9. What if I feel discomfort while taking part in this research?
We understand this is a difficult time which can be very distressing. If you feel particularly anxious or find it distressing to consider changes that the COVID situation has brought about you, please do not hesitate to quit this survey.

10. What if I have any questions?
We very much appreciate your valuable input, and we hope you stay well. This statement has been developed to protect people who agree to take part in research studies. If you have a complaint/concern, please contact MHCJEF001@myuct.ac.za.

Consent form for the recording of interview – to accompany information sheet given to the participant

Evaluating The Impact of Innovative Technologies on the Delivery and Affordability of South African Affordable Housing.

Jeffrey Jr. Mahachi

Degree of Masters of Philosophy in Construction Economics and Management University of Cape Town

I ....., confirm the following:

1.	I have read the information sheet provided by the researcher and thus understand the projects aims and objectives.	
2.	I am participating in this project voluntarily and understand that I may withdraw from the interview at any time if I so do wish.	
3.	I acknowledge and understand that confidentiality will be maintained.	
4.	I have been asked permission to record this interview and have given my permission.	
5.	I understand that this data is accessible to other researchers only if they honour the confidentiality agreement.	

Participant

Date .....

Signature of participant .....

Name of participant .....

The organisation of participants.....

Researcher:

Name: .....

Signature: .....

Date: .....

Appendix B
Expert Interview Questions:

Expert Interview Protocol

Name: *Jeffrey Jr. Mahachi*
Student No.: *MHCJEF001*
University: *University of Cape Town*
Degree*:* *Master of Philosophy in Construction Economics and Management*
Target: *Home Developers/Policymakers*

1. What are some current challenges or barriers you are faced with during the development of affordable housing?
2. What have you found to be reasons for delays in the delivery and/or cost overruns during affordable housing development?
3. Do you often use innovative technologies to aid during the development of affordable housing? Please elaborate on your answer.
4. Innovative technology often consists of *Object-Oriented Design, BIM, GIS, Smart Sensors, Project Portfolio Management, 3D Laser Scanners, Drones, Modular Construction, and 3D Printing.* Which of these technologies do you use? And to what extent?
5. What are the advantages to each of these technologies stated in Question 3?
6. What are the disadvantages to each of these technologies stated in Question 3?
7. Based on your experience and professional opinion, do you think innovative technology is fully utilized within the South African housing sector? Please elaborate on your answer.
8. Do you foresee any challenges or barriers that may arise with adopting innovative technologies within the context of South African housing projects?
9. Does the adoption of innovative technology positively or negatively impact the delivery process of South African affordable housing? Please elaborate on your answer.
10. Does the adoption of innovative technology positively or negatively impact the cost of South African affordable housing? Please elaborate on your answer.

Appendix C

Randomly Selected Interview Transcript (Expert):

1. What are some current challenges or barriers you are faced with during the development of affordable housing?

The first challenge is the availability of the land and the quality of the houses that are delivered on the ground. Summarised into three main issues, the land, the finances, and the quality of the houses that are provided.

2. *What have you found to be reasons for delays in delivery and/or cost overruns during affordable housing development?*

Number 1 is the payment of contractors. Most of the time, particularly for affordable housing, the government is the client, and their payments are very late.

Number 2 is the availability of quality materials. There is a huge shortage of materials or affordable materials. The materials are very expensive. One needs to investigate alternative ways of having materials for building construction. Some of the cost overalls are possibly due to the long delays in the project, so what you end up with is contractors cutting corners and claiming for some of the things that are not supposed to be claimable. For example, contractors would put a lot of costs into the foundation so at the end of the day the costs are much higher than what was budgeted for. So, there is a kind of collusion between the professionals and the contractors and that ends up with a cost.

3. Do you often use innovative technologies to aid during the development of affordable housing? Please elaborate on your answer.

The one thing which I have indicated is the availability of affordable materials. The use of innovative building materials can assist in providing alternative methods of construction which are more affordable. The usage of those innovative building technologies is not only affordable but also quicker to construct. Therefore, if they are quick, you can deliver a product at a much more affordable cost. The third thing is that the quality of the construction is much better. You have your products either premanufactured or preassembled in a controlled manufacturing environment, or if they are done on-site, the method of assembling the products is much better than your conventional brick-and-mortar. So, I do use innovative technologies during the development because they give me a better method of constructing and delivering affordable houses.

4. Innovative technology often consists of Object-Oriented Design, BIM, GIS, Smart Sensors, Project Portfolio Management, 3D Laser Scanners, Drones, Modular Construction, and 3D Printing. Which of these technologies do you use? And to what extent?

The ones that I have used here are modular construction, 3D printing and to a limited extent, building information modelling. Most of the affordable housing projects that I work on are based on modular construction. 3D printing I would say I use it to a limited extent for now because it is still a new technology, and it has not yet matured to a level that people expect it to be used daily. It is still perceived to be a technology that is going to take people's jobs, although it promises to deliver houses that are of better quality and cost-effective. Now, costs are probably still higher than conventional brick-and-mortar. The reason is that it is a new technology and like any other new technology when you are starting it off, the cost will probably be much higher than any other technology. So, from this perspective, I have used 3D printing and I believe that it is the future of construction.

Modular construction, yes, in many of the affordable housing as well as other social infrastructure.
Drones to a limited extent, but I also believe that with drone technology, you would be able to simplify and do your work much more effectively and efficiently. For example, in your project management and construction management, you can utilise drones to monitor the construction on site. So, I think drone technology is a good technology, although I have not used it that much. I see that there is huge potential for utilising those technologies.

5. What are the advantages of each of these technologies stated in Question 4?
As I mentioned maybe earlier on, the best advantage of these technologies, number 1, is a better-quality product than the conventional construction methods. The second point is a more effective life cycle cost. When I talk of a life cycle cost, I am not only talking about construction costs. If you look at construction costs alone, innovative building technologies are probably more expensive than conventional brick and mortar. So, if you are going to look at the cost of building a house, that cost will probably be higher for innovative building technology than for conventional brick and mortar. However, if you look at the whole life cycle cost from the time you started the whole project and looked at the identification of materials, logistics, actual construction, maintenance, and demolishing, then innovative building technologies offer a better life cycle cost than your conventional brick and mortar. You are going to find that with your innovative building technologies, you might be able to utilise more effectively things like your waste materials, reduction of waste on-site, reduction of time to deliver the product, reduction of energy consumption especially these days with power shortages, and fewer carbon emissions. So, if you consider all of these things and put them into a cost, then that cost is much lower than the cost of conventional brick and mortar.
So, it is very critical when people talk about a cost, they don't talk about a construction cost, but they look at the whole life cycle. So, life cycle costing is much better for innovative building technologies.
I have also touched on the other indirect benefits in the life cycle costs such as energy efficiency because most of these innovative building technologies have good thermal properties, so it is much cooler in summer and warmer in winter. So, they have got good thermal properties, which makes them more energy-efficient houses. There are fewer carbon emissions, which is what you want with climate change, so you help with the reduction of CO2 emissions. I have also mentioned construction time. With an ordinary brick-and-mortar, you would probably deliver a house in 6 months, but with your technologies, you may be able to deliver it in a few weeks, maybe 2-4 weeks. So, these are some of the advantages that one can look at.
So broadly speaking, there are many opportunities. And some people may perceive that these technologies reduce employment and jobs will be lost. But I think that is a wrong assumption because as I have mentioned earlier on if you look at the life cycle cost, some of the jobs might be removed from the site to somewhere else. So, you are looking at the utilisation of waste materials. If you are looking at waste materials it means that people can go and identify waste materials. So, you have created jobs in people identifying waste materials. So, you are creating many other jobs, not necessarily on the construction site but elsewhere within the life cycle cost. And with these technologies, I believe that you are also able to attract the youth and women who feel that construction sites are dirty and dangerous. So, with most of these modular constructions as well as some of the newer technologies such as 3D printing, you can attract the youth, who can then see that construction sites can also be smart sites.
Overall, there are many opportunities and advantages of these technologies.

6. What are the disadvantages to each of these technologies stated in Question 4?

I would want to say that there are limited if any, disadvantages to the technologies. The main ones that would come to mind are that some of the materials that are used in some of these technologies come from overseas. So, if you have materials coming from overseas that becomes problematic. You have to wait for the materials to come from China which will take 3 months or so, for logistics to come through to South Africa. So that can be a barrier to innovative technology.
The second disadvantage is if one is not careful in terms of some of the technologies, it is quite difficult to remodelling a house, specifically alterations or additions to a house. Some of the technologies are not able to alter the house. In some cases, it would be better to do it with brick and mortar because now the technology that was used maybe can no longer be found and the person that did it is no longer available to provide you with the materials required to remodel the house. So, alterations, additions, and remodelling might be compromised with innovative technologies.
The third disadvantage is that with some of the technologies if they are not implemented correctly as required, the advantage that we saw as good quality may be compromised and become bad quality. So, you need people who are trained adequately to be able to understand these technologies so that they can implement them correctly. So, with bad implementation, the reputation of the technologies is compromised, and people may think that the technology is not correct.
Last, but not least, which I think is the most important thing is that with most of these technologies, the biggest challenge is the social acceptability and perceptions of these technologies. People have perceptions that these technologies are inferior to brick and mortar. This is because of the knock-on effect – if I knock on the wall and hear a knock-on sound, I have the perception that this a poor-quality material and therefore, as a beneficiary or end user, I am not interested in that technology because of the perception that it might be a poor-quality material. So that for me is the biggest disadvantage of innovative building technology – the perceptions of the people around the technologies.

7. Based on your experience and professional opinion, do you think innovative technology is fully utilised within the South African housing sector? Please elaborate on your answer.
I think the technology is used in less than 5% of the projects, although the government itself has put in place many policies and many initiatives to promote the utilisation of innovative building technologies. But the implementation thereof is not happening. For example, some 7 years ago the government set a quota of 60% of all social infrastructure projects that should be built using innovative technologies. 5 years later, less than 5% was done using innovative technologies. So, the uptake is not happening. The reason for these leverages comes back to the previous question of the disadvantages, which talks more about the perceptions of people, particularly in housing. You will find that innovative building technologies have been used a lot in the social infrastructure space. You look at many clinics and schools, they have been built using innovative building technologies. I can even give you a simple example – not far from my place, one of the shopping centres, a KFC was built, and in a few weeks the KFC was finished. Are you aware that all the McDonald's built in the Republic of South Africa, were built using innovative technologies? And McDonald's have been built in South Africa since 1999. You can look at any McDonald's, even the first McDonald's built in South Africa, have you ever been to any McDonald's and seen a bad quality? They are all built using innovative building technologies. McDonald's has a heavy-traffic kitchen, yet have you ever seen it disintegrating, or have you ever seen a single crack? Now if I were to build you a house using the same technology as is used for McDonalds, what would be your problem? It would be cool in summer and warm in winter. No one goes to McDonalds and starts knocking on the walls saying the wall doesn't sound good. But those are the social infrastructures. Clinics are also

built using innovative building technologies. Similarly, a child who goes to school does not knock on the walls and say this wall does not sound great. But for a house, because this is the biggest investment for most people, there is no uptake for affordable housing. They would want brick and mortar. But in social infrastructure, the uptake is very high. So, most of the technologies have been successful in clinics, schools, McDonalds, and everywhere else, but not in housing because it is people's biggest investment. So, it is a perception issue that we need to deal with.
Overseas innovative building technologies are being used. They don't even call them innovative building technologies because it is their conventional. In North America and some parts of Europe, they build using Timber. But a timber house would not be accepted in South Africa because we have a feeling that brick and mortar is the best. So, the uptake is not that good.

8. Do you foresee any challenges or barriers that may arise with adopting innovative technologies within the context of South African housing projects?
the few technologies that we have, if not implemented correctly will enhance people's perceptions. So, if someone builds a house using the technologies, and for some reason does it badly, people will say, "We have told you that these technologies are rubbish". So, the uptake will be even worse. So, whoever is implementing it now, must implement it correctly. This is the key for us to be able to succeed in the implementation of it.
The one interesting thing as opposed to many countries in Africa and some of the other developing countries is that we have one of the best building regulations in the world, which allow you to use innovative building technologies. Unfortunately, the municipal officers involved in approving the plans do not know the building regulations. This is one of the barriers – lack of understanding. But this does not only apply to the municipal officers. There is also a lack of knowledge and understanding from the professionals and contractors. So, it starts with the professional, because if the professional does not understand innovative building technology, who will tell the consumer or end user that you can use this technology? The professional should be able to tell them of alternatives to the conventional brick and mortar, and the benefits thereof. The professional does not know, so they become a barrier to implementing these innovative technologies. And if the contractor is not trained adequately, they will stick to the brick-and-mortar to not spoil their reputation. We can change this mindset by changing our tertiary education system so that people, whilst they are still in tertiary school, know that there are other ways of doing construction besides brick and mortar. They can then be the ones to suggest innovative building technologies when they start working for contractors or professional consulting companies.

9. Does the adoption of innovative technology positively or negatively impact the delivery process of South African affordable housing? Please elaborate on your answer.
This will summarise all that I have said. I believe that the adoption of innovative building technology will positively impact the delivery process in South Africa. I have spoken mostly about the speed of construction, particularly when you look at modular construction. Currently, the housing backlog in South Africa is 2.5 million, and this housing backlog is increasing every year. This is a figure from a few years ago. Currently, this figure could maybe even be at 3 million. This figure is continuously increasing. How else are you going to eradicate the housing backlog? You need fast ways of constructing and delivering things on the ground. Only innovative building technologies can provide a high speed of construction. I am not discarding the brick-and-mortar, but you cannot quickly build and complete a wall about 2.4 meters high. With modular construction, you can put maybe 3 panels in a few minutes, clip them and you are done with the wall. So, for us to be able to eradicate this housing backlog, we need to

embrace innovative building technologies. So, I think that innovative building technologies will positively affect the delivery of affordable housing in South Africa.

10. Does the adoption of innovative technology positively or negatively impact the cost of South African affordable housing? Please elaborate on your answer.
As I mentioned before, the cost is embedded in time, maintenance, energy efficiency, and many other things. So, it will positively affect that because now I am going to investigate the whole lifecycle. If I build a house, yes, the construction costs will be higher, but I will not need a heater to warm the house in winter. I will not require a fan to cool the house in summer. So, these are some of the cost reductions that I will enjoy in the future. So yes, it will positively impact the costs in ensuring that the costs of delivering the houses will be brought down.

Appendix D
Blank Questionnaire Survey:

Survey Questions

This questionnaire survey has been drafted with the purpose of obtaining accurate and relevant findings that will help investigate the impact innovative technologies have on the delivery and affordability of South African Affordable housing. These findings will contribute to Jeffrey Jr. Mahachi's master's research paper which is conducted through the University of Cape Town.

The questionnaire can be completed in approximately 10 minutes. All useful comments that will aid the researchers in carrying out the study are welcome. Participation in the research will take the form of completing a questionnaire which does not pose any known risks (minimal risk) and does not request any sensitive information from the participant. All subjects of this research and any information that you shall provide will be protected with unreserved confidentiality. Ethical procedures require your full consent in order to participate in this survey. Please read the following information sheet regarding the conditions required for
your participation:

• Please understand that your participation in this research is entirely voluntary. If you choose not to participate, there will be no negative consequence. If you choose to participate but wish to withdraw at any time, you will be free to do so without any negative consequence. However, the researchers would be grateful if you would
participate in this study.

• There is a risk that you may share some confidential information by chance, or that you may feel uncomfortable. You do not have to answer any question or take part in the questionnaire if you feel the question(s) are too personal or if talking about them makes you uncomfortable. There is not any risk of emotional, upset, or stigmatisation that you encounter during this survey.

• All the information provided is confidential, no identifiable data either from participants or company such as names will be collected. Each participant will only be identified by a number. The data will only be used for the sole purpose of this research, and therefore the raw data shall only be known to the researchers. No raw
data that you provide about your projects will be shared with anybody outside. Data collected will be analysed and clustered in an aggregate form, and identification information will never be used in a publication or presentation. The data will be stored on the designated, password-protected hard drive and cloud storage and
shared only with the researchers. After completing this research, raw data will be destroyed.

• There is no direct benefit to you by participating in this research. The knowledge gained may benefit the public in the future.

This document acknowledges you understand of your rights as a participant in this study, which the researcher has explained to you prior to signing the document. Should you have any queries or questions for clarification purposes about the study, do not hesitate to contact Jeffrey Jr. Mahachi on mhcjef001@myuct.ac.za
Your timely response will be appreciated.

* Required

Appendix E
Blank Online Questionnaire:

1. I have read the above information and agree to participate in this survey. *

Mark only one oval.

- ◯ Yes
- ◯ No

General Information

2. Educational Background of the Respondent. *

Mark only one oval.

- ◯ Certificate – Diploma with Grade 12
- ◯ Higher National Diploma (Technikon/University of Tech)
- ◯ Undergraduate
- ◯ Postgraduate
- ◯ Other: _____

3. Designation of Respondent. *

Mark only one oval.

- ◯ Director
- ◯ Management
- ◯ Technical staff
- ◯ Other: _____

4. Field of Respondent. *

Mark only one oval.

- ◯ Architect
- ◯ Engineer
- ◯ Construction Manager
- ◯ Quantity surveyor
- ◯ Other: _____

5. Year of experience in Affordable Housing (e.g. 20 years). *

_____

6. Year of Establishment of the firm (e.g. 30 years). *

_____

7. Service provided by the firm (Please, select all that apply). *

Check all that apply.

- ☐ Project Owner/Client
- ☐ Consultant
- ☐ Project Management
- ☐ Developer
- ☐ General Contractor
- ☐ Sub-contractor
- ☐ Specialist
- ☐ Supplier
- ☐ Other: _____

8. In the last five years, how many gap housing projects has your company been involved with? *

_____

9. To what extent do you agree with this statement. The lifecycle cost of South African gap housing is not really affordable for low-middle-income households. *

Mark only one oval.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly agree

10. What are the causes of the high costs or unaffordability of South African gap housing? *

Check all that apply.

- ☐ Lack of technological adoption
- ☐ Lack of technological awareness
- ☐ Too much rework during development
- ☐ High costs of building material
- ☐ Prolonged periods between conception and construction
- ☐ Miscommunication and ineffective collaboration between design team and construction team

11. To what extent do you agree with this following statement? Delays in the development of South African gap housing are a recurring event. *

Mark only one oval.

- ◯ Strongly disagree
- ◯ Disagree
- ◯ Neutral
- ◯ Agree
- ◯ Strongly Agree

12. In your experience, what do you find causes delays in construction delivery? *

Check all that apply.

- [ ] Miscommunication and ineffective collaboration between design team and construction team
- [ ] Lack of technological adoption
- [ ] Lack of technological awareness
- [ ] Too many errors in material design, causing rework
- [ ] Inefficient monitoring of construction projects
- [ ] Prolonged periods to assemble designed structures

13. Please list the technologies you may have used to help you during the development of gap housing. *

14. What are some possible advantages to technology adoption during the design and construction of affordable housing? *

Check all that apply.

- [ ] Fewer Costs
- [ ] Faster delivery
- [ ] Higher quality of housing delivered
- [ ] Improved communication and collaboration
- [ ] Improved project monitoring
- [ ] Less rework in designs or construction errors

15. Please indicate the level of familiarity with the following technologies. *

Mark only one oval per row.

	Not at all	Low	Average	High	Very High
Building Information Modelling (BIM)	◯	◯	◯	◯	◯
Geographic Information Systems (GIS)	◯	◯	◯	◯	◯
Smart Sensors	◯	◯	◯	◯	◯
3D Laser Scanners	◯	◯	◯	◯	◯
Drones	◯	◯	◯	◯	◯
Modular Construction	◯	◯	◯	◯	◯
3D Printers	◯	◯	◯	◯	◯
Object-Oriented Programming	◯	◯	◯	◯	◯
Project Portfolio Management	◯	◯	◯	◯	◯

16. Please indicate the level of use of the following innovative technologies in the design and construction of houses in these projects. *

Mark only one oval per row.

	Not at all	Low	Average	High	Very High
Building Information Modelling (BIM)					
Geographic Information Systems (GIS)					
Smart Sensors					
3D Laser Scanners					
Drones					
Modular Construction					
3D Printers					
Object-Oriented Programming					
Project Portfolio Management					

17. Please indicate the challenges and barriers to adopting the following innovative technologies in the design and construction of affordable housing projects (Please, select all that apply) . *

Mark only one oval per row.

	High cost (Initial / maintenance / operation)	Lack of guidelines and standards	Incompatibility with other technologies	The tendency to maintain current technologies	Unaware of this technology
Building Information Modelling (BIM)	◯	◯	◯	◯	◯
Geographic Information Systems (GIS)	◯	◯	◯	◯	◯
Smart Sensors	◯	◯	◯	◯	◯
3D Laser Scanners	◯	◯	◯	◯	◯
Drones	◯	◯	◯	◯	◯
Modular Construction	◯	◯	◯	◯	◯
3D Printing	◯	◯	◯	◯	◯
Object-Oriented Programming	◯	◯	◯	◯	◯
Project Portfolio Management	◯	◯	◯	◯	◯

18. Please indicate the challenges and barriers to adopting the following innovative technologies in the design and construction of affordable housing projects, (Please, select all that apply) Cont'd... *

Mark only one oval per row.

	Lack of incentives	Lack of Technical Knowledge	Lack of awareness of availability	Lack of policy and regulation
Building Information Modelling (BIM)				
Geographic Information Systems (GIS)				
Smart Sensors				
3D Laser Scanners				
Drones				
Modular Construction				
3D Printing				
Object-Oriented Programming				
Project Portfolio Management				

19. What are the impacts of adopting the following technologies on the delivery of South African gap housing? *

Mark only one oval per row.

	High Negative Impact	Negative impact	No Impact	Positive Impact	High Positive Impact
Building Information Modelling (BIM)					
Geographic Information Systems (GIS)					
Smart Sensors					
3D Laser Scanners					
Drones					
Modular Construction					
3D Printing					
Object-Orientedd Programming					
Project Portfolio Management					

20. What are the impacts of adopting the following technologies on the costs of South African gap housing? *

Mark only one oval per row.

	High Negative Impact	Negative impact	No Impact	Positive Impact	High Positive Impact
Building Information Modelling (BIM)					
Geographic Information Systems (GIS)					
Smart Sensors					
3D Laser Scanners					
Drones					
Modular Construction					
3D Printing					
Object-Orientedd Programming					
Project Portfolio Management					

Appendix F

Statistical Analysis Shapiro Wilk Test:

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Question 2	.438	100	<.001	.588	100	<.001
Question 3	.274	100	<.001	.655	100	<.001
Question 4	.291	100	<.001	.709	100	<.001
Question 5	.189	100	<.001	.842	100	<.001
Question 6	.212	100	<.001	.901	100	<.001
Question 7	.151	100	<.001	.916	100	<.001
Question 8	.281	100	<.001	.612	100	<.001
Question 9	.310	100	<.001	.824	100	<.001
Question 9	.310	100	<.001	.824	100	<.001
Question 10	.181	100	<.001	.862	100	<.001
Question 11	.362	100	<.001	.737	100	<.001
Question 12	.162	100	<.001	.903	100	<.001
Question 14	.111	100	.004	.935	100	<.001

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Q.15 BIM NO.	.202	100	<.001	.912	100	<.001
Q.15 GIS NO.	.163	100	<.001	.915	100	<.001
Q.15 Smart Sensors NO.	.184	100	<.001	.910	100	<.001
Q.15 3D Laser Scanners NO.	.175	100	<.001	.910	100	<.001
Q.15 Drones NO.	.191	100	<.001	.914	100	<.001
Q.15 Modular Construction NO.	.170	100	<.001	.915	100	<.001
Q.15 3D Printers NO.	.176	100	<.001	.913	100	<.001
Q.15 OOP NO.	.175	100	<.001	.913	100	<.001
Q.15 PPM NO.	.197	100	<.001	.906	100	<.001

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Q.17 BIM NO.	.256	100	<.001	.812	100	<.001
Q.17 GIS NO.	.271	100	<.001	.842	100	<.001
Q.17 Smart Sensors NO.	.222	100	<.001	.799	100	<.001
Q.17 3D Laser Scanners NO.	.247	100	<.001	.783	100	<.001
Q.17 Drones NO.	.275	100	<.001	.769	100	<.001
Q.17 Modular Construction NO.	.213	100	<.001	.869	100	<.001
Q.7 3D Printers NO.	.219	100	<.001	.830	100	<.001
Q.17 OOP NO.	.241	100	<.001	.847	100	<.001
Q.17 PPM NO.	.251	100	<.001	.864	100	<.001

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Q.18 BIM NO.	.324	100	<.001	.822	100	<.001
Q.18 GIS NO.	.266	100	<.001	.862	100	<.001
Q.18 Smart Sensors NO.	.272	100	<.001	.861	100	<.001
Q.18 3D Laser Scanners NO.	.244	100	<.001	.864	100	<.001
Q.18 Drones NO.	.256	100	<.001	.865	100	<.001
Q.18 Modular Construction NO.	.197	100	<.001	.873	100	<.001
Q.18 3D Printers NO.	.250	100	<.001	.866	100	<.001
Q.18 OOP NO.	.242	100	<.001	.870	100	<.001
Q.18 PPM NO.	.261	100	<.001	.860	100	<.001

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Q.19 BIM NO.	.291	100	<.001	.757	100	<.001
Q.19 GIS NO.	.314	100	<.001	.776	100	<.001
Q.19Smart Sensors NO.	.224	100	<.001	.850	100	<.001
Q.19 3D Laser Scanners NO.	.241	100	<.001	.840	100	<.001
Q.19 Drones NO.	.279	100	<.001	.838	100	<.001
Q.19 Modular Construction NO.	.245	100	<.001	.802	100	<.001
Q.19 3D Printers NO.	.256	100	<.001	.843	100	<.001
Q.19 OOP NO.	.215	100	<.001	.858	100	<.001
Q.19 PPM NO.	.264	100	<.001	.774	100	<.001

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Q.20 BIM NO.	.293	100	<.001	.830	100	<.001
Q.20 GIS NO.	.306	100	<.001	.835	100	<.001
Q.20 Smart Sensors NO.	.273	100	<.001	.877	100	<.001
Q.203D Laser Scanners NO.	.263	100	<.001	.881	100	<.001
Q.20 Drones NO.	.270	100	<.001	.868	100	<.001
Q.20 Modular Construction NO.	.298	100	<.001	.798	100	<.001
Q.20 3D Printers NO.	.288	100	<.001	.838	100	<.001
Q.20 OOP NO.	.237	100	<.001	.880	100	<.001
Q.20 PPM NO.	.254	100	<.001	.836	100	<.001

a. Lilliefors Significance Correction

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Q.16 BIM NO.	.171	100	<.001	.910	100	<.001
Q.16 GIS NO.	.168	100	<.001	.915	100	<.001
Q.16 Smart Sensors NO.	.219	100	<.001	.862	100	<.001
Q.16 3D Laser Scanners NO.	.207	100	<.001	.854	100	<.001
Q.16 Drones NO.	.182	100	<.001	.879	100	<.001
Q.16 Modular Construction NO.	.168	100	<.001	.905	100	<.001
Q.16 3D Printers NO.	.228	100	<.001	.844	100	<.001
Q.16 OOP NO.	.216	100	<.001	.844	100	<.001
Q.16 PPM NO.	.179	100	<.001	.912	100	<.001

a. Lilliefors Significance Correction

Appendix G
Ethics approval sheet:

Application for Approval of Ethics in Research (EiR) Projects
Faculty of Engineering and the Built Environment, University of Cape Town

ETHICS APPLICATION FORM

Please Note:
Any person planning to undertake research in the Faculty of Engineering and the Built Environment (EBE) at the University of Cape Town is required to complete this form **before** collecting or analysing data. The objective of submitting this application *prior* to embarking on research is to ensure that the highest ethical standards in research, conducted under the auspices of the EBE Faculty, are met. Please ensure that you have read, and understood the **EBE Ethics in Research Handbook** (available from the UCT EBE, Research Ethics website) prior to completing this application form: http://www.ebe.uct.ac.za/ebe/research/ethics1

APPLICANT'S DETAILS		
Name of principal researcher, student or external applicant		Jeffrey Jr Mahachi
Department		Construction Economics and Management
Preferred email address of applicant:		MHCJEF001@myuct.ac.za
If Student	Your Degree: e.g., MSc, PhD, etc.	MSc
	Credit Value of Research: e.g., 60/120/180/360 etc.	
	Name of Supervisor (if supervised):	Dr. Alireza Moghayedi and Kathy Michell
If this is a researchcontract, indicate the source of funding/sponsorship		
Project Title		Evaluating The Impact of Innovative technologies on the delivery and affordability of South African Affordable Housing

I hereby undertake to carry out my research in such a way that:

- ☐ there is no apparent legal objection to the nature or the method of research; and
- ☐ the research will not compromise staff or students or the other responsibilities of the University;
- ☐ the stated objective will be achieved, and the findings will have a high degree of validity;
- ☐ limitations and alternative interpretations will be considered;
- ☐ the findings could be subject to peer review and publicly available; and
- ☐ I will comply with the conventions of copyright and avoid any practice that would constitute plagiarism.

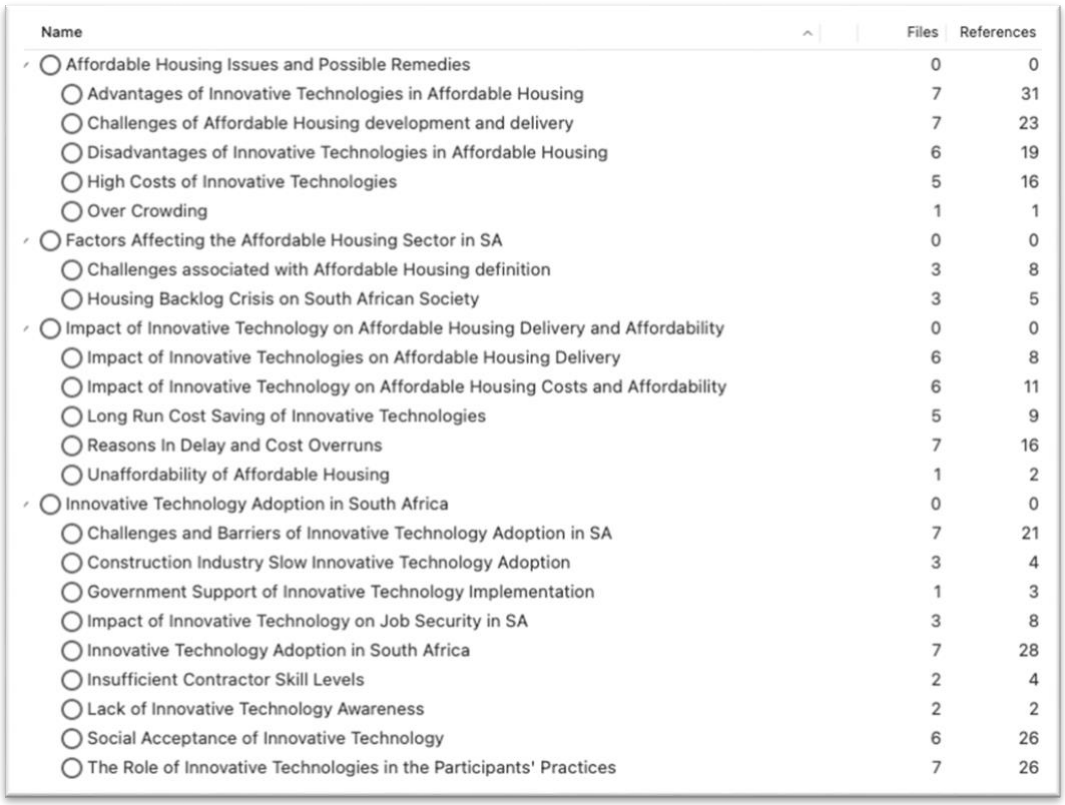
APPLICATION BY	Full name	Signature	Date
Principal Researcher/ Student/External applicant	Jeffrey Jr. Mahachi		26/05/2022
SUPPORTED BY	Full name	Signature	Date
Supervisor (where applicable)	Alireza Moghayedi		26/5/2022

APPROVED BY	Full name	Signature	Date
HOD (or delegated nominee) Final authority for all applicants who have answered NO to all questions in Section 1; and for all Undergraduate research (Including Honours).	Dr. Frank K. Ametefe		2022/06/13
Chair: Faculty EIR Committee For applicants other than undergraduate students who have answered YES to any of the questions in Section 1.			

Page **1** of **1**

Appendix H

Thematic Analysis: Parent and Child Nodes Generated from Thematic Analysis



Name	Files	References
Affordable Housing Issues and Possible Remedies	0	0
Advantages of Innovative Technologies in Affordable Housing	7	31
Challenges of Affordable Housing development and delivery	7	23
Disadvantages of Innovative Technologies in Affordable Housing	6	19
High Costs of Innovative Technologies	5	16
Over Crowding	1	1
Factors Affecting the Affordable Housing Sector in SA	0	0
Challenges associated with Affordable Housing definition	3	8
Housing Backlog Crisis on South African Society	3	5
Impact of Innovative Technology on Affordable Housing Delivery and Affordability	0	0
Impact of Innovative Technologies on Affordable Housing Delivery	6	8
Impact of Innovative Technology on Affordable Housing Costs and Affordability	6	11
Long Run Cost Saving of Innovative Technologies	5	9
Reasons In Delay and Cost Overruns	7	16
Unaffordability of Affordable Housing	1	2
Innovative Technology Adoption in South Africa	0	0
Challenges and Barriers of Innovative Technology Adoption in SA	7	21
Construction Industry Slow Innovative Technology Adoption	3	4
Government Support of Innovative Technology Implementation	1	3
Impact of Innovative Technology on Job Security in SA	3	8
Innovative Technology Adoption in South Africa	7	28
Insufficient Contractor Skill Levels	2	4
Lack of Innovative Technology Awareness	2	2
Social Acceptance of Innovative Technology	6	26
The Role of Innovative Technologies in the Participants' Practices	7	26